

**INNOVATION IN INDUSTRIALIZED CONSTRUCTION
PROCESSES AS A SOURCE OF COMPETITIVE ADVANTAGE
WITH A CASE STUDY OF AN INDUSTRIALIZED SYSTEM IN
COLOMBIA**

by

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ABSTRACT

Computer data acquisition, automation, robotics and other advanced technologies are fundamental sources of competitive strategies in today's market. Construction, with frequent severe environmental conditions and its unique projects, has been slow to adopt automation technologies. However, internal and external trends are pushing some kinds of building construction into these technologies.

This thesis investigates the impact of advanced technology on construction firms. The present condition of technology in construction is studied, and strategies that firms may adopt to become competitive in the technological market are discussed using two models of competitive strategy.

A number of construction engineering firms in Colombia are using a recently developed industrialized construction system to gain a competitive advantage. An analysis of this new technology is used to support this research.

Thesis Supervisor: David H. Marks
Title: Professor and Head of the Department of
Civil Engineering

DEDICATION

To my parents, brothers and sister.
A mis padres hermanos y hermana.
To the paper carrier.
Al que reparte periodico.
To the floor cleaner.
Al que limpia pisos.
To those whom find the way no matter how.
Al que no acepta la palabra dificultad en el logro de una meta.
To the analytic.
Al analitico.
To the native.
Al indigena.
To Colombia and its people, for whom I fight in silence, carrying a
thunderous message.
A Colombia y su pueblo por quienes lucho en silencio llevando un
mensaje de trueno.
To the idea of the superman and the eternal return of all things.
Al mas poderoso de los hombres.
To F.A.R.S.
A F.A.R.S.
To PRIMOS.
Al grupo PRIMOS.
To the sportsmen.
Al deportista.
To her.
A ella.
To Friedrich Nietzsche.

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CHAPTER I

INTRODUCTION

1.1 PURPOSE OF INVESTIGATION

The purpose of this thesis is to investigate the potential for competitive advantage resulting from technological innovation in the construction engineering industry within a generally applicable framework. The powerful forces driving construction into innovation are studied, and new concepts of systems for industrialized construction are introduced. In addition, the current state of the art in data acquisition and automation in construction is discussed, and the process of gaining and maintaining a competitive advantage with technological development is examined using two models of competitive strategy. The findings are applied to a case study in which a Colombian firm has acquired an industrialized construction system in order to gain competitive advantage in the building construction market.

1.2 THE THESIS IN OUTLINE

This thesis is organized as follows:

The next chapter discusses the increasing importance of technology as a source of competitive advantage in construction. The current trends demanding innovation in construction are presented. The slow process of technological innovation in construction engineering and the disadvantages and advantages of such innovation will serve

as a framework to discuss the needs that this industry faces in research and development.

The third chapter provides background information on the industrialized construction industry. The process of construction and manufacturing of five systems of *in situ* casting are presented, and the influence of these systems in the technological development of the different sectors of the construction industry is discussed.

The fourth chapter of this investigation presents a detailed study of the competitive advantages which can result from technological innovation in the civil engineering industry. To do so, the technological policy and the potential for automated real-time data acquisition, process control and robotics for remote, field operations, such as those on construction projects, are addressed. Applications of these technologies to industrialized construction for *in situ* casting of concrete are discussed.

The fifth chapter considers the impact of technological development on the value chain of construction firms involved with industrialized construction systems. The sources of competitive advantage are discussed, and the role of technological competition is analyzed through a case study of a recently developed industrialized construction system, which some construction engineering firms are using to establish technical leadership and competitive advantage. Features of this case are reviewed in terms of the concepts developed in chapters two, three, and four.

Finally, chapter six presents the conclusion of this study and provides a summary of the main issues found through this investigation.

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CHAPTER II

INCREASING IMPORTANCE OF TECHNOLOGY AS A SOURCE OF COMPETITIVE ADVANTAGE IN CONSTRUCTION

Today's technological markets are forcing the construction industry into innovation. The following conditions are encouraging constructors to try new technologies and to improve construction processes. First, some competitors are now committed to technology development and innovation; second, the complexity of construction materials is increasing; third, computer applications are playing a major role in construction tasks, such as scheduling, project control, accounting, etc; fourth, the complexity of construction projects is increasing; fifth, clients want to receive more from their constructors for their investments.

This chapter describes how new competition in the construction engineering industry is pushing the industry toward the development of more advanced technologies. Strategies for developing advanced construction technologies and the utilization of these technologies to gain a competitive advantage are proposed. The different elements of competitiveness are presented through a model of competitive strategy, and the potential advantages and disadvantages of introducing new technology to construction are discussed.

2.1 COMPETITION IN THE CONSTRUCTION INDUSTRY

As has happened in other industries, to remain competitive, construction engineering must begin to incorporate advanced technologies into construction practice. Advanced technology is surely not the only task to be accomplished; construction firms must become more efficient in other ways also. But the new technologies available from other engineering disciplines and sectors of the economy offer a clear potential for improving the effectiveness of designs and the efficiency of construction projects.

The construction industry is fragmented: a high percent of construction firms have no permanent employees or payroll. The traditional system of open bidding on public projects also makes the industry highly competitive. Construction is a mature industry with the attendant problems of increased cost competition and decreased profits. Competition in construction is often reciprocal. Many firms have very similar strategic positions, and rely only on operating differences to gain competitive advantages. In the construction industry in Western countries, technology is often considered as a means to improve efficiency rather than a potential source of competitive advantage. In industrialized Eastern countries, however, managers appear to see technology as a primary source of competitive advantage. [14. South].

A competitive analysis of the construction industry will further highlight the intense competitiveness of the construction business. According to the Porter framework for competitive

analysis, an industry has a high level of competitive pressure when: 1) rivalry among firms is high; 2) when it is easy to enter; 3) when both buyers and suppliers have high bargaining power; and 4) when there is a threat of substitute products. [12. Porter, 1985]. As shown in Figure 2.1, many of these conditions fit specific segments of the construction industry.

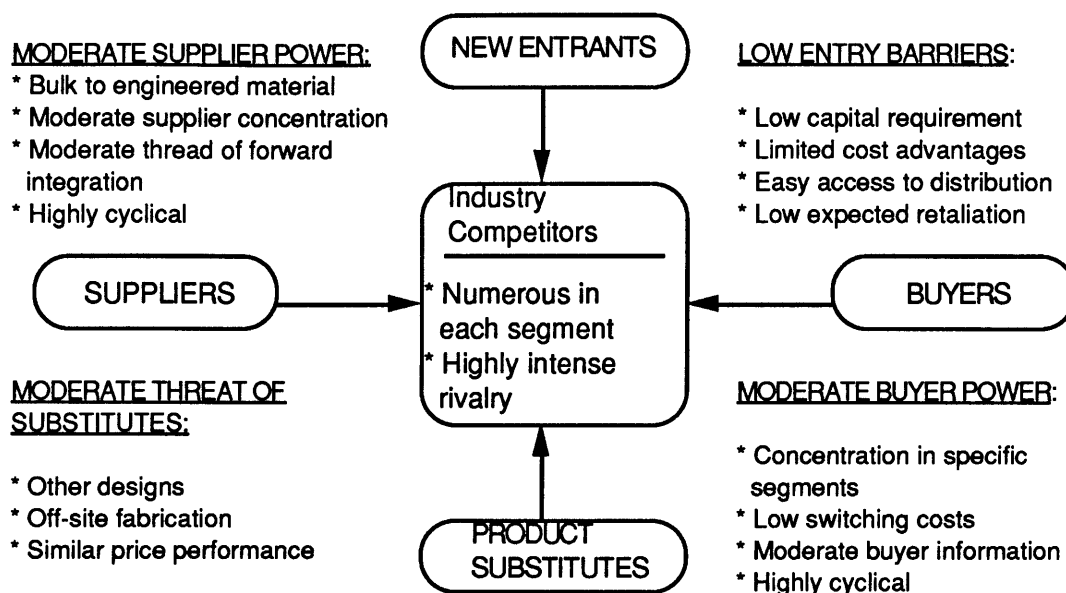


FIGURE 1. ELEMENTS OF COMPETITIVENESS IN THE CONSTRUCTION INDUSTRY. (Porter, 1980.)

Many key changes in the industry are forcing a shift in competition from labor and subcontractors management to technological issues. Six trends are increasing the demand for innovation in construction.

First, owners in the manufacturing and process industries, struggling to regain competitiveness in domestic and international markets, are demanding "better performance of the construction input in quality and quantity for the money" [8. Business Roundtable] and are pointing out that advanced technology is one way to get more value.

Second, the facilities that owners need are becoming much more complex and therefore demand greater technological sophistication to build them. Examples include the control and life safety aspects of building, automated manufacturing facilities, clean rooms, new systems for communications and data transfer, and complex facilities to provide better water treatment or to burn solid waste. High-tech projects are the growth market for construction.

Third, the size and relative stability of the construction market in Western countries are making it more attractive to Eastern contractors. This has increased the rivalry among companies in Western industrialized countries who have lost share of international market and domestic market.

Fourth, the low entry barriers in construction are encouraging construction firms to experiment with specialization in order to reduce competition. Technology creates barriers to new entrants in construction because it raises economies of scale in the technological development function itself, by quickening production of constructive facilities and raising the investment required for the acquisition of the technology to competitors. A firm that possesses a revolutionary construction method can also license its technology to

competitors under favorable terms of its chosen and thus dissuade further entry barriers into its business segment. A construction company that is known for completing large housing projects within budget and time and for offering extensive fireproof warranties for the units, for example, creates extremely high-barriers to new entrants that are not able to offer such warranties. By specializing, companies increase efficiency and barriers against new entrants into specific segments of the market.

Fifth, product substitution is pushing the construction industry into technology. Construction companies with know-how in a specific process technology are able to reduce price performance, to compete with technical basis, and to easily substitute the market of firms that do not possess the same or better technology development. Substitution applies equally to products and processes. Companies with the Meccano construction technology, for example, (see section 3.5.4. for the description of the Meccano system) are able to produce a series of five, or six floor buildings in less than three quarters of the time employed by competitors with regular construction procedures. Meccano technology is a clear substitute for other construction processes in building facilities, such as jails, apartment buildings or any project that involves series of the same design.

Finally, due to the fact that there are numerous competitors in each segment of the construction industry and intense rivalry among them, some companies with focus strategy and good management strategy are pursuing new technologies and

specializations to avoid the rush of competitors of the present construction business. International competitors, specially from Eastern developed countries, have sensed the increasing importance of technological development in construction, and they have borrowed technologies from other disciplines. The development of useful classification systems has helped researchers define appropriate topics and objectives, and guide industry and government in developing effective, coordinate long-term programs of research.

2.2 COMPETITIVE STRATEGY AND TECHNOLOGY DEVELOPMENT

Strategy includes three levels: the firm, the business unit, and the functional unit.[5. Glueck]. Corporate strategy focuses on defining the business in which to compete and on obtaining and allocating resources. The line of business strategy concerns how to compete in each chosen business. Functional strategies describe the actions in each of the functional areas, to support the line of business and corporate strategies.

"Competitive strategy is the search for a favorable competitive position in an industry, the fundamental arena in which competition occurs. Competitive strategy aims to establish a profitable and sustainable position against the forces that determine industry competition." [12. Porter, 1985]. Companies in search for competitive advantage with technological development can follow one of the three main strategies in the business:

low cost strategy, differentiation strategy, or focus strategy. Low cost strategy can be defined as the acquisition of leadership position in the market by offering the lower cost to owners. In order to achieve cost leadership, companies manage the cost drivers such as learning curves and economies of scale. Construction companies with industrialized systems for *in situ* casting of structures , for example, use three basic elements in their business: steel, concrete, and intensive labor. The firms with better skills in lowering the costs of these elements achieve substantial advantage not only among general constructors but also among other competitors with industrialized construction systems.

The second strategy, differentiation, is basically the capability of firms to offer something unique and valuable to buyers. The introduction of a revolutionary rather than evolutionary industrialized construction system into the construction market is a good example of differentiation strategy. However, by offering a “different” product, firms do not automatically obtain competitive advantage. Service and technology go together in the acquisition of such an advantage from a new product. It is important to state at this point that differentiation strategy can be obtained not only through a new product but also through a new or modified process.

The combination of the two strategies given above leads the industry to a third strategy known as focus or niche strategy. A company that owns an industrialized construction system commonly does not sustain competitive advantage in the long run just by differentiation or by having the lower cost. To compete

followers and current rivals are quick to copy new technology to reduce costs . By focusing on a specific buyer segment and by efficiently using the learning curve, the company can sustain its competitive advantage. In other words, both cost and differentiation can be used to provide the focus strategy.

Differences in the characteristics of construction technology are significant for the process of both developing new technology and using it to gain competitive advantage. This includes both product and process technology. The products of construction are generally immobile, complex, durable, costly, and characterized by a high level of social responsibility. Buyers of construction have specific needs. The need for unique designs to meet these needs, combined with the characteristics of constructed products and the strong relationship between the product and the process required to produce it, create several opportunities for competitive advantage.

Construction operations are dispersed on sites, dependent on unique and often dynamic designs, subject to variable working conditions and constantly reconfigured. This makes the technology very different from manufacturing. One classification of construction technology identified the following components: 1) materials and permanent equipment resources; 2) construction applied resources; 3) project requirements and constraints; and 4) construction processes.[15. Tatum]. These characteristics of the process technology for construction highlight its complexity and the many potential sources of competitive advantage. New types of

designs for constructed facilities, improved integration of design and construction, and improved construction processes each offer the chance for a designer or contractor to better meet the needs of the owner. These strategies illustrate using technology to expand to new markets or to win in existing markets based on differentiation, cost, or focus.

2.2.1 STRATEGIES FOR USING ADVANCED CONSTRUCTION TECHNOLOGY TO GAIN COMPETITIVE ADVANTAGE

The three generic types of competitive advantages identified by Porter, considered along with the characteristics of constructed products and processes, suggest ways that construction firms can use advanced technology to gain competitive advantages. These strategies recognize the differences in construction markets, constructed products, and the technologies needed to perform diverse construction operations. The strategies described in this section concern using advanced product or process technology to gain competitive advantage.[16. Tatum].

Cost Leadership Based on New Process Technology

New process technology offers potential competitive advantages for construction firms. Using advanced construction technologies, such as computer tools for improved integration or construction robotic, can make firms more productive in performing the same operations, and therefore give competitive advantages based on cost leadership (see section 4.1). Broadly viewed and

creatively applied, new process technologies cannot only improved the productivity of a targeted operation, but also produce many unanticipated advantages. For example, one contractor's development and use of technology for partially automated grading improve productivity, allowed greater flexibility in equipment assignment, assisted in operator training, and provided a basis for improving the efficiency of other type of operations.

Differential Technical Capability

Construction firms can use advanced technology to win projects based on a unique capability to perform a specific type of work. For example, companies with specialized welding and heat treating skills have dominated markets for the fabrication and erection of large vessels and contractors are using special technical skills regarding clean rooms to win jobs in this growing market. Although these are traditional construction markets, the selection of firms winning these types of projects is increasingly based on a differential capability to either design better facilities or construct them more rapidly, more reliably, or less expensively.

Technology-based Specialization

Experience, technical expertise, and investment in specific technologies can give a construction firm advantages in a focused market. The differences in the construction technology for differing operations appear to foster specialization in the construction industry. There are many different types of subcontractors. Some

have total capability and other concentrate on field operations. Mechanical subcontractors, who generally design, fabricate, and erect duct-work for heating and ventilating systems, illustrate the first type. Form-work subcontractors are an example of the second type. Their competitive advantage comes from an ability to construct concrete form-work at a lower cost than general contractors. Experience, technical knowledge, and an inventory of form systems and materials give this advantage. The result is to differentiate the firm based on a reputation for innovative approaches and solutions.

2.2.2 STRATEGIES FOR OBTAINING ADVANCED CONSTRUCTION TECHNOLOGIES

Strategies to obtain advanced construction technology are one of many functional strategies that must support an effective business strategy. With this functional support, managers implementing line of business strategies seek to gain any of the possible types of competitive advantage. This section describes some of the potential strategies for getting and nurturing advanced construction technology [16. Tatum].

Persistent Process improvement

Consistent and intense, efforts to improve operations can create competitive advantages based on cost leadership. This strategy involves improvements of existing technology and the use of available technology in all possible ways. One example of this is a

construction firm with an industrialized system for *in situ*-casting where foremen erector, mechanics, superintendents, and managers consistently study each operation for greater efficiency either by technological innovation of mold performance in the factory or improved management techniques at the site. This firm developed new technologies for the partial automation of assembling upper floors panels at the construction site, used existing equipment in construction of new facilities such as stadiums and poultry farms, and cut mobilization costs in the factory - all for significant improvements in productivity.

An innovation policy through the company value chain is a key element of persistent process improvement. As identified in investigations of innovation in other industries, providing organizational freedom and resources to consider innovative approaches, and removing the fear of failure, are important elements.

Project-driven Technology development

The technical challenges of specific construction projects offer a powerful incentive for the development of advanced construction technology. Construction firms noted for their technical prowess, for example, often have a policy of bidding extremely high and starting again with a new evaluation of many creative alternatives once a project is won. This evaluation includes considering applying construction technologies in new ways to solve the specific technical problem posed by the project. For example, the contractor for an

outfall project planned and sold a segmental method of installation despite requirements for the pull method in the specifications. This method decreased investment in specialized equipment, lowered risk, and improve the ability to respond to differing bottom conditions.

Internal Construction R&D

Investments in the development of new technology can produce competitive advantage based on unique technical capability or lower costs. This strategy involves setting priorities based on the problems of existing operations and developing new technology by allocating funds and effectively managing development activities.

Interaction With a Lead Supplier

Contractors can create competitive advantage by working with lead suppliers to develop new technologies for construction. This involves analyzing current construction operations to identify problems that could be solved by suppliers, convincing a progressive supplier that developing new technologies to solve these problems could offer a significant opportunity for sales to contractors, and working with this "lead supplier" in the role of "lead user"[13. concept presented by Von Hippel] to help develop and initially implement the new technologies. The suppliers bring expertise regarding a specialized technology and the contractor provides a real-world test bed. The contractor's field personnel may

work directly with the supplier's engineers on actual projects to further develop the technology for construction applications. The contractor must keep the process active to gain further advantages when the technology initially developed with the lead supplier is adopted by others.

Forward Technical Integration

Establishing strong links with designers to improve constructability and foster product innovation in constructed facilities can create new technologies for contractors. A key role for contractors is the development of the new process technologies that the product innovations may require.

Backward Technical Integration

A contractor can develop new technologies by establishing strong links with owners to determine specific needs. This strategy creates differentiation by unique capability to meet the owners special needs. It can result in either new hardware technologies to meet special technical requirements or new management technologies.

Brokering for Technology Leadership

Construction firms can develop a strategy of broad and persistent efforts to adopt new technologies. Brokering for technology leadership involves: emphasis of the "gatekeeper" role to identify available technologies; adapting beneficial technologies

from other industries and other segments of construction; being the first to try something new, even when a beneficial application is not immediately apparent; and fully exploiting these "borrowed" technologies to decrease costs and to develop new capabilities. A construction company with industrialized systems has incorporated its technology into the construction of mammoth tanks for the water supply company in Colombia. Today, more than fifty percent of sales are related to tank construction for water treatment plants and oil deposits.

Brokering for Technology Followership

Aggressive efforts to be an effective technology follower can bring new technologies to construction firms. This requires quickly adopting new but proven technology. Possible steps includes imitating the technology developed by others and licensing applicable technology. American contractors have followed this strategy regarding new technology for soft ground tunneling and are now examining the potential adoption of robots for construction.

2.3 FACTORS PROMOTING OR DISCOURAGING TECHNOLOGICAL ADVANCES IN CONSTRUCTION

The demonstrated benefits of innovation in manufacturing and in other industries indicate excellent opportunity and potential for research on technology in construction. The increased understanding of fundamental mechanisms for construction innovation expected from this investigation will contribute to

essential advancement and increase international competitiveness in this vital industry. Contrasting construction with other industries is necessary before examining mechanisms for innovation in construction.

Construction's differences includes both advantages and disadvantages for innovation. Although additional investigation is necessary to determine the extent and the influence of these differences, they suggest hypotheses for investigation of potential mechanisms for innovation in construction.

2.3.1 FACTORS PROMOTING TECHNOLOGICAL ADVANCES

Compared with manufacturing, the construction industry presents important advantages for innovation. These advantages include several elements which researchers have found to encourage innovation in other industries.

Despite the fact that there are some similarities among construction projects, each includes a unique situation and requirements that leads to challenge. This could promote innovation by forcing examination of new technologies for each new and challenging project.

When project organization provides for engineering and construction integration through the early assignment of experienced personnel, the consideration of construction experience during the design of the facility can simplify construction process requirements and decrease cost.

Construction firms typically involve relatively low capital investment, which may allow high flexibility for the adoption of new technologies. In construction firms with high investment, such as heavy civil contractors, technological advancements can result from small incremental investments. For example, the addition of automated control to existing grading equipment has greatly improved productivity and quality.

Most construction companies include a pool of technologically experienced personnel. These superintendents and engineers can provide a depth of knowledge concerning the subtle methods required for productive field operations.

Construction's strong emphasis on process rather than hardware solutions to technical problems limits barriers to imitation. New process elements of technologies can spread rapidly without patent restraints. This allows quick diffusion and promotes incremental improvement. However, it also removes incentives for innovation by any one firm.

The work operations of construction present inherent flexibility for improvement. Production processes do not create rigid restraints, as in manufacturing. In fact, the unique elements of each project require the use of differing methods for many operations. These differences offer the opportunity to improve past methods.

2.3.2 FACTORS DISCOURAGING TECHNOLOGICAL ADVANCES

Despite these potential advantages, several elements of construction have restrained innovation. These characteristics of the industry, individual firms, and specific construction projects each work against technical progress.

The low capital intensity of the industry limits interest in investment for automation. If a new technology appears to lessen flexibility for work on several types of projects, construction managers resist this possible advance because of the potential restraints. High levels of competition in the construction industry limit profits available for investment in advanced technology. In addition, the inability to protect advances in the construction process with patents may discourage investment.

In both geographic regions and specialty segments of the construction industry, competitive conditions may limit willingness to take the technical and financial risks associated with new construction technologies. If a firm is maintaining an adequate share of a market (regional or by specialty operation), the pressures to take the risks of innovation are reduced.

The institutional framework of construction can be cited as a barrier to innovation. This framework includes the large number of construction firms, the contractual and legal background, the treatment of risk and liability, the regulatory influences, and the organization of labor. Each of these factors argues for a static approach to technology.

The fragmentation of the industry, with a large number of firms specialized both by geographic region of operation and by type of construction, limits the resources available to individual firms for innovation. The legal framework of the industry, with an increasing concern for limitation of liability, provides strong incentives for technological inertia. Increasing regulatory requirements, particularly those for safety and environmental protection, divert capital potentially available for new technologies, and encourage proven methods. Uncertain craft jurisdiction complicates the introduction of new methods or equipment.

Tradition strongly influences many construction organizations. Managers, estimators, engineers and superintendents each see many incentives to repeat methods which proved successful on past projects. This results in a limited acceptance of "champions" for innovation and a fear of risk and liability. It also creates a means orientation of specific methods for specific operations which can prove very difficult to break.

A high variation of work volume in the cyclical construction industry restrains capital investment and limits economies of scale. This create a reluctance to make commitment which limit flexibility to respond to seasonal or economic changes in markets.

With some exceptions, suppliers to the construction industry have not created the technological advancement that their counterparts have made in other industries. Uncertain market conditions foster a reluctance to invest in further advancements to the equipment and tools used by construction.

The factors promoting or discouraging technological advances in construction, indicate that many conditions of the construction industry have been also found in the innovative process of other industries. Many companies and projects are innovative. Despite this, the use of consistent technology for many operations and a decreasing share of world market for some industrialized countries, indicates the necessity for increased technological advancement. The levels of technological progress in other countries, and the advantages resulting from the advanced technologies, may make technology a key basis for competition in important future construction markets.

2.4 SUMMARY AND PRACTICAL APPLICATIONS

Significant forces are now driving the engineering and construction industry toward advanced technology. The availability of new technology that offers major potential benefits and the increasing complexity of constructed products are two key technical forces.

Several strategies presented in this section provide the way to develop advanced construction technology and use it to gain competitive advantages. The potential competitive actions include using new technology to offer new products and to penetrate new markets, to achieve cost advantages, and to differentiate the firm based on unique technical capability. But first the firm must get the advanced technology. This section also offers strategies to do this; some are entrepreneurial in pursuit of improvements where there

are no obvious problems; some involve responding to technical challenges or using someone else's good ideas; others take a bigger picture in advocating integration. There is no single best strategy for either developing or using advanced technology; gaining the possible advantages requires vision, flexibility, and tenacity.

How can managers seeking new sources of competitive advantage apply these strategies? They can first consider them as options in charting the future course of their firms. The strategies can also guide the emergence of a new functional responsibility in construction firms - that of managing technology. Finally, if others are winning jobs in unexplained ways, something we may see more often, the strategies can help in analyzing what is happening and in deciding how to respond.

To do their part, researchers need to further explore the development and use of advanced technology to gain competitive advantages in construction. Further development and testing of technology strategies similar to those proposed in this section would increase understanding of how advanced technology can improve the competitiveness of construction firms. These strategies could assist researchers and policy makers in setting priorities for the development of advanced construction technology and managers in increasing the technical capabilities of construction firms. There is also a need to direct academic attention to the management of advanced technology in construction and to the use of technology to improve integration over the many phases of a project.

Technological advancement is an important means for the construction industry to meet challenges of increased cost-effectiveness and improved international contractors competitiveness. A progressive construction industry can assist in solving in-house problems with manufacturing and process industries, infrastructure, and mass transportation.

Prior investigations of innovation in construction have emphasized the barriers created by the industry's institutional framework. Fragmentation, regulation and labor provide excuses for inertia. Despite these, some segments of the industry have advanced construction technology. Studies of heavy civil transportation and building construction indicate progress. Specific examples from power construction describe innovations in response to challenges presented by individual projects.

The construction industry presents both advantages and disadvantages for innovation. Any of these form hypotheses for future investigation for construction innovation. The advantages include engineering and construction integration, necessity and challenge, low capital investment, capability and experience of personnel, process emphasis, and variation in methods. Among the disadvantages in construction for innovation are: investment reluctance, institutional frame work, seasonal and economic cyclicity, and the role of suppliers.

Each of these advantages results in a hypothesis for possible important mechanisms of innovation in construction. Conversely,

the avoidance of any of the disadvantages noted could prove critical in fostering construction innovation.

CHAPTER III

CURRENT STATUS AND PROCESSES OF INDUSTRIALIZED CONSTRUCTION SYSTEMS FOR IN SITU CASTING OF CONCRETE UNITS

Industrialized systems for *in situ* casting of structures are known world-wide. They are used for different purposes depending upon the output of construction by type of work and by sector of use in each country. This chapter offers background information on these industrialized systems of construction and their influence in the technological development of the construction industry. Finally, fundamental issues related to the construction and assembly process of five industrialized systems for *in situ* casting of concrete structures are discussed.

3.1 BACKGROUND AND CENTRAL ISSUES

Construction output may be classified according to whether the client is a public authority or a private body, individual or collective. Unfortunately, statistics on the relative importance of these two sectors are available only in a few industrialized countries.

In many developing countries, public expenditure on construction is the only expenditure known with any degree of accuracy, at least as far as the central or provincial government is

concerned. It is difficult to generalize from the scattered data available, but it is reasonable to assume that the public sector dominates in construction engineering works, where it may account for higher percentage of the total annual output, and that the private sector is the more important in housing, building for industry and commerce and -in developing countries with a long tradition of religious or missionary institutions- in building for education and health.

In a majority of industrialized countries, including most European countries and Israel and Japan, a considerable volume of housing is financed, directly or indirectly, by central or local government. The same applies to building for education, for health and for other social welfare services. In countries where large sectors of industry and services are nationalized, the share of the public sector is considerably more than fifty per cent.

The situation began to change at the beginning of the 1950s, when it was realized that the gap between the demand and the supply of building, hitherto regarded as an emergency following the disruption and destruction of the second world war, was in fact a long-term problem to be solved only by long term changes in the structure of demand and the way in which this demand was allocated to the construction industry. At the same time, governments and other public institutions in Eastern countries and Europe started to work on reviewing existing regulations, introducing more flexible methods of awarding contracts and formulating conventions for the dimensional coordination and

standardization of building materials and components that might be internationally accepted, such as wood, metal structure, concrete structure and bitumen for roofing waterproofing, etc. There was also move to reassess the purpose and scope of training for employment at all levels in the construction industry, and in general to sponsor, encourage and support what became known as the " industrialization of building".

The public sector played an essential role in this, specially in Europe, Korea, China and Japan with no little involvement of the United States of America and Mexico. It may be regretted that the professions associated with the industry (architects, engineers, etc.) did not, at least until recently, sufficiently associate themselves with it. At the risk of oversimplifying the position, it might be said that the converse was true in the centrally planned economies, where the publicly owned construction industry took the lead in introducing changes and securing the support of the higher policy-making bodies.

It was natural that the public sector should be prominent in the move towards industrialized building. Only the public sector had a sufficient volume of demand for building to justify the research and development work necessary to launch new techniques or to create new products. Only the public sector was able to plan its requirements in advance and ensure the continuity of demand industrialized building. The drawback was that the public sector was exposed to changes in policy and to political control. Governments were tempted to use the public sector as an

indirect regulator of demand, which sometimes had unfortunate effects on the construction industry.

The technical policies and contractual arrangements in force in the public sector affect the private sector as well, although with a considerable time lag. In only a few countries in the upper range of economic and social development could it be claimed that the private sector is ahead of the public sector as regards contractual procedures or the use of advanced technologies. One of the main problems in the remaining countries is how to increase the influence that the public sector exercises over the private sector and how to spread the "know-how" accumulated in a few central places throughout an industry that, by its very structure tends to resist change.

3.2 KEY ROLE OF PUBLIC HOUSING IN PROMOTING INDUSTRIALIZATION

Industrialized systems in the construction industry are relatively new and result from the recent need for the fast completion of large housing projects. Before 1945 any construction project was handled by companies with traditional construction capabilities. In the late 50s research in the mechanical engineering field in Europe developed "new systems" of construction able to reduce cost and save time in large housing projects. These new systems of construction were widely accepted and the market for industrialized housing grew rapidly. However, the market in some countries was not prepared to absorb these new construction

technologies, principally for cultural reasons, and in these countries the implementation process has been slow.

3.3 MARKET FRAMEWORK FOR INDUSTRIALIZATION OF CONSTRUCTION

Where are industrialized housing systems used? The output of construction by type of work and by sector of use is a good framework to locate industrialized construction systems in the market. Four separate categories may be identified. They are:

- (1) The international-modern;
- (2) The national-modern;
- (3) The national conventional;
- (4) The traditional.

The first two categories are more frequently found in developed countries, while the last two tend to be found more often in third world countries.

3.3.1 INTERNATIONAL-MODERN

The international-modern category is the easiest to define and the term is largely self-explanatory. It includes major international class buildings, such as public buildings in a prestige class, and high quality private buildings in the large urban centers of big metropolis. It is international in that it employs technologies borrowed from the most advanced construction firms and that it is largely -sometimes exclusively- in the hands of international firms. It depends heavily on imports of expensive materials and

components, of sophisticated plant and machinery, and of professional, and supervisory skills. It conforms with international quality standards; it is based on internationally accepted contractual documents and practices, and so on.

3.3.2 NATIONAL-MODERN

The national-modern category may be regarded as a scaled-down version of the international sector. It caters to both public and private demand in major urban centers. Although it is based on technologies imported, the quality standards have been scaled down to local conditions. It requires a large number of skilled operatives in various building trades. It employs the simpler mechanical aids and plant (concrete mixers, block-making machines, hoists scaffolding, etc.). It is handled mainly by national firms whose organizational pattern and technical competence is often a pale copy of the middle-range construction firms. The national-modern category includes a large proportion of minor public buildings, (schools, health centers, police stations, etc.), private commercial and industrial buildings, secondary roads and other minor civil engineering works. In some countries the national-modern category uses almost exclusively locally produced building materials and components, although a small proportion of imported fitting and equipment may be employed.

3.3.3 NATIONAL-CONVENTIONAL

The national-conventional category is not easy to define. It is in essence transitional and the term "intermediate technology" is often used to describe it. It is characterized by a mixture of traditional materials and techniques and a few selected modern inputs, such as cement for floors and wall blocks, corrugated iron or asbestos-cement sheets for roofing, hard wood for joinery, glass, paint and other finishes. Such materials are used in varying amounts according to the sophistication of the client. For a number of technical and administrative reasons, the public authorities do not generally finance building in this category, but it covers a large proportion of privately built dwellings in urban in semi-urban centers, as well as a good deal of rural infrastructure and community development. Most of the work is carried out by local constructors and by small, emerging indigenous contractors who are starved of working capital, simple plant and tools and basic management skills. The national-conventional category of building provides an ideal training ground for local artisans to acquire the necessary experience to undertake more modern construction.

3.3.4 TRADITIONAL

The traditional category of building predominates in rural areas and, in some cases, in the areas between rural and urban settlements. It lies almost entirely outside the monetary sector, and the labor is mostly unskilled men carrying out "do it yourself" jobs. Traditional building is greatly influenced by the national-

conventional category as soon as transport facilities improve communications between urban and rural centers, or the rural dweller has migrated to the town.

It will be observed that the four categories have been described both in terms of the technological features of construction and of the branches of the construction industry that carry it out. The two aspects are closely connected, but the relationship is not a direct one.

3.4 NEED FOR COORDINATED POLICY TO PROMOTE INDUSTRIALIZATION

Without some estimate of the breakdown of output by technological level and by category of construction, it is impossible to formulate a coherent policy for the development of the industrialized construction industry. The different categories respond differently to changes in technological level of demand. Resources released by one category cannot necessarily be used by another; the situation may occur, for instance, where idle capacity in the national-modern category may coexist with excessive demand for construction in the national-conventional category or vice versa. There may also be a lack of effective demand for a category of construction, for example, when pilot projects for social housing (improperly called low-cost housing) are carried out in the national-modern category at prices well above the means of the social class for which they were originally intended.

Planning for the future of the industrialized construction industry must be based on a reasonable quantitative assessment of the present structure of construction output and the construction industry and on consistent assumptions about the probable rates at which each category will grow. Targets may then be set, based on past experience and on the growth potential of individual categories. The desired volume and technological level of demand may be influenced by direct policy action, specially in the public sector; estimates of resources required to achieve these targets may be made for each category. Finally, specific constraints may be eliminated by concerted short and long-term action.

Industrialized systems for *in situ* casting and regular systems of construction still compete in the private sector of the construction engineering market where, as a result of technical and cost advantages, developers worldwide have found the industrialized systems increasingly attractive. Contractors are especially interested in using industrialized systems in the national-modern and national-conventional categories for big projects in disaster areas, for military housing, and for governmental housing projects. Many developing countries, such as Mexico, Korea, and Brazil, heavily use industrialized systems of construction for high-quality private buildings and houses in the international-modern category. In Japan, for example, construction firms use these systems for *in situ* casting in big cities for apartment buildings, large housing projects, jails, and schools in the international-modern and the national-modern categories .

However, in the United States these technologies for *in situ* casting are rarely used.

3.5 FIVE INDUSTRIALIZED METHODS FOR IN SITU CASTING OF HOUSING STRUCTURES

Even though more than twenty systems for construction of series of houses or buildings exist in today's market, only five systems for *in situ* casting of housing structures are widely known. These are:

- (1) Tunnel
- (2) Lift
- (3) Con-tech
- (4) Fast-tech
- (5) Meccano.

In order to clarify the concept of industrialized construction, I present a short description of each technology

3.5.1 TUNNEL METHOD

This method of construction consists of two strong forms with "L" shape made out of metal with specifications to support high concrete pressure and daily transportation from place to place in the construction site. Due to the fact that the forms are very heavy, a crane or cranes are necessary to carry the forms.(See Exhibit 1-A, 1-B). When the forms are ready, the pour is made. The result is a series of tunnels made in concrete. When the concrete dries, the forms are disassembled and the process is repeated. After the

forms are removed the subcontractors begin to work making front, back, and inside walls; installing electric, hydraulic heater and drain systems; assembling window frames, door frames and glasses; painting and finishing the apartment or house, etc. In other words, once the tunnel is made, the process becomes the same as the methods of regular construction.

3.5.2 LIFT METHOD

This system is specially suitable for building construction. After the foundation is ready, it is covered with Styrofoam sheets to separate the future concrete walls from the foundation concrete. (See Exhibit 2-A). The purpose of these Styrofoam sheets is to prevent the pouring of the walls from interacting with the concrete of foundation. Then the reinforcing steel for the walls is placed onto the Styrofoam. In addition, steel cables connect wall and upper floor panels for lifting. These cables are also used to assure proper alignment between walls and floors during the final construction process. Forms are placed and the pour of multiple first floor walls is made. When the concrete walls have cured, they are covered with Styrofoam sheets and then, panels are cast on top of the cured wall panels. Then, the whole process is repeated. When the roof panels are finally cast and cured, a powerful hydraulic system lifts the building, as shown in Exhibit 2-A and 2-B. As the floors are raised, the interconnected cable systems erect and properly align the walls into final position.

When the different concrete panels are in place, the joints are welded, some of the internal walls that still need to be done are built, and the different services are installed following regular procedures of construction.

3.5.3 CON-TECH METHOD

This system of construction, unlike the two systems discussed earlier, does not need heavy equipment to raise buildings or to move the forms. The mold consists of small steel panels that can be carried by one or two people. While assembling the forms, other teams incorporate the electric and the plumbing systems, as well as the door and the window frames as needed. Because of the size of the panels, all of the unit walls can be cast with this system at once. After few hours when the mold is ready the pour is made.

Approximately twelve hours after the pour, the mold is disassembled. The result is a monolithic wall structure in which a large percentage of the plumbing, heating, and electric systems is incorporated to the concrete structure. After that, the upper floor is made and the whole process is repeated, following regular methods of construction. Finally, finishing the units follows regular construction methods.

3.5.4 FAST-TECH AND MECCANO

The main difference between these two systems is the material that the panels are made of. Fast-tech uses aluminum sheets 3/16" thick, while Meccano uses steel sheets 1/8" thick to

make the panels. Both systems, like Con-tech, consist of small standard panels and some special panels to make the mold. This condition makes it easy to meet any architectural design. Unlike Con-tech, Meccano and fast-tech have developed a new technology in which the roof, if it is a house, or upper floor of the apartments, if it is a building, is also assembled with panels to the wall panels at the same time. More specifically, the system relates to a building process and provides a means for *in situ* casting of structures such as houses, buildings, dikes, stadiums, and the like. It is specially suitable for building in series of large projects. More particularly, the system consists of a total mold formed by a number of parts to be assembled at the construction site. The mold is assembled around a metal structure which remains embedded in concrete once the mold has been filled. The cast structure that results is a solid, steel-reinforced monolith. Once the concrete structure is dry, the mold is partially disassembled, taken to the next construction site, and the process is repeated.

Exhibit 3, Figures 1 to 13, illustrates the complete process of construction for a series of houses:

Figure 1 represents the foundation planking. the different pieces which make up the foundation planking together form the shape of the foundation to be built.

Figures 2 and 3 show a mold assemblers team (MAT), a plumbing team (PT), an electrical team (ET) and an steel erection teams (SET), working simultaneously in their different tasks.

Figure 4 shows the assembly jig which is basically the plan in the scale 1:1 of the house or apartment to be built. The jig indicates in detail reinforcement specifications, wall locations and their thickness, window and door sizes, electric and water supply appliances, switches, etc. The different teams are responsible for following this jig instructions with an accuracy of +/- 1 mm.

Figure 5 clarifies how the assembly jig serves as a guide to indicate the location of walls and therefore the place where the steel erection team must put the shiplaps or overlaps for the walls' steel.

Figure 6 depicts the detail of the assembly jig as a guide for the installation of plumbing and electrical accessories as well as appliances.

Figure 7 shows the concrete pouring and leveling.

Figure 8 shows the jig back in place again and the system to inset the guides "Us" for the mold walls. This procedure can be done

one hour after the pouring or at the beginning of the next day.

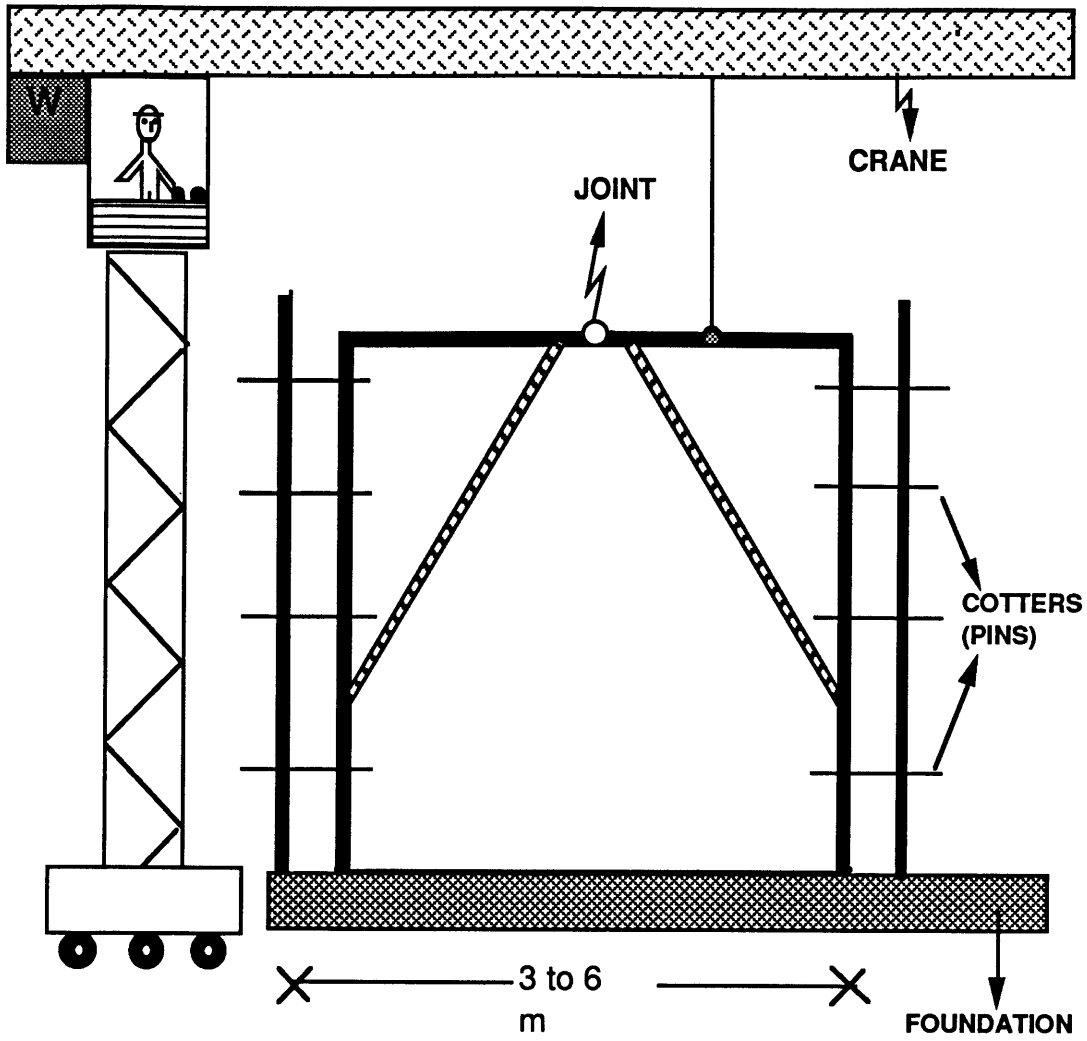
Figure 9 shows the foundation and steel erection .At this point the unit is ready for the mold to be assembled.

Figure 10 shows the steel erection ready, the electric and plumbing accessories in place, and the mold assembly in process.

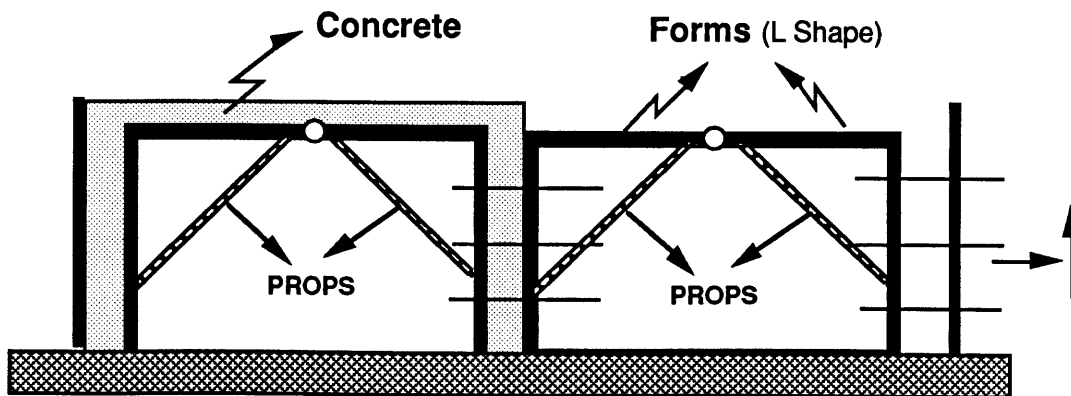
Figure 11 shows the detail of the mold as a unit, with the walls and roof integrated, and ready to receive the concrete. After the walls are full the SET puts in the reinforcement for the roof, which takes fifteen minutes, and then the pouring is completed.

Figure 12 shows the unit twelve hours after the pouring. The cast structure that results is a solid, steel-reinforced monolith.

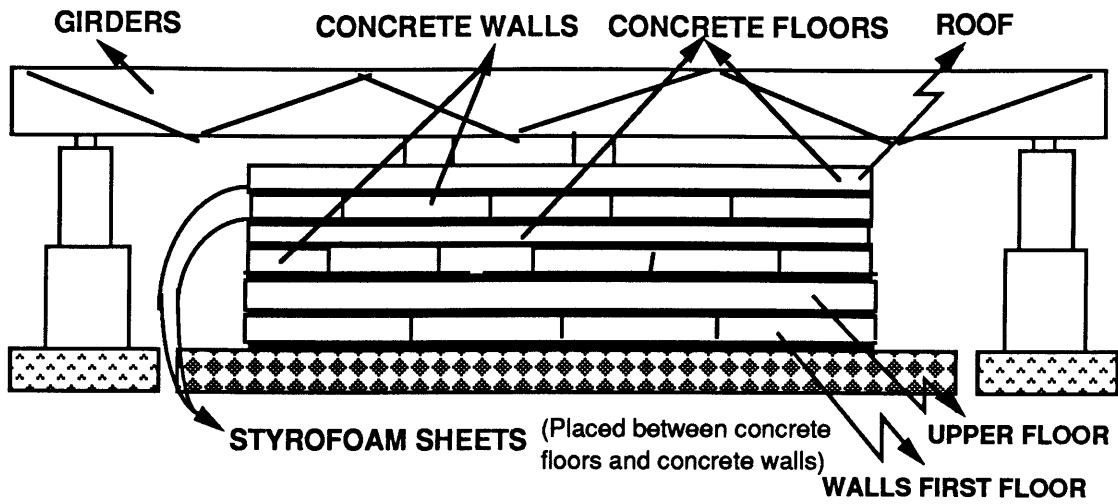
Figure 13 shows the final product after details of painting, carpeting and other appliances have been installed.



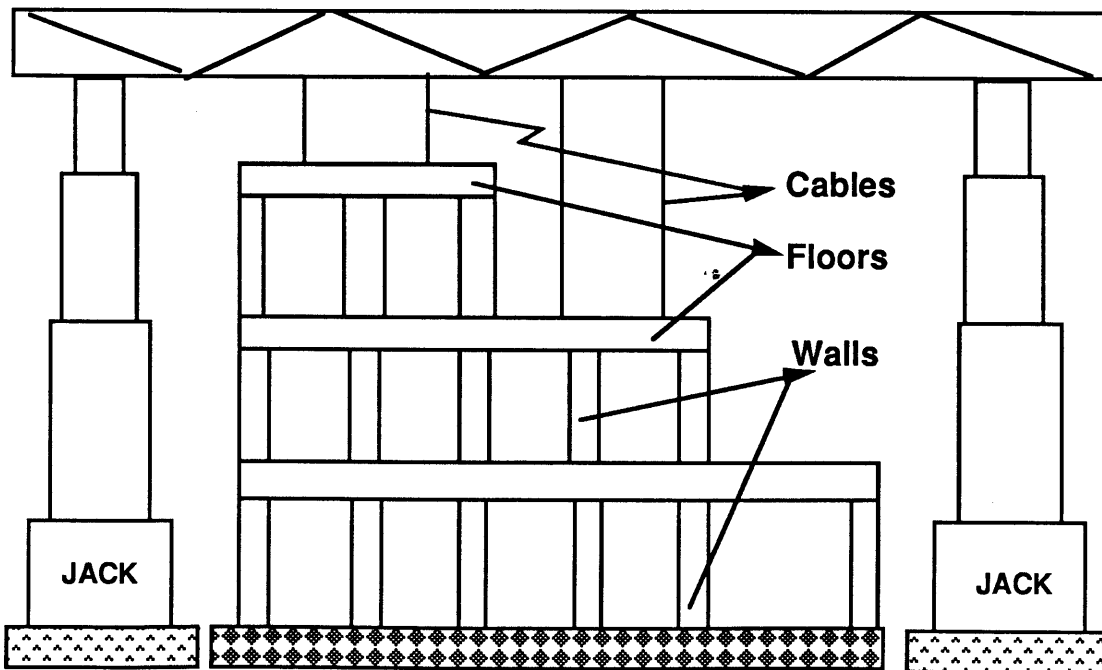
< Exhibit 1-A > TUNNEL SYSTEM



< Exhibit 1-B > TUNNEL SYSTEM



< Exhibit 2 -A >
(Before lifting)



< Exhibit 2 -B > LIFT SYSTEM

(After Lifting)

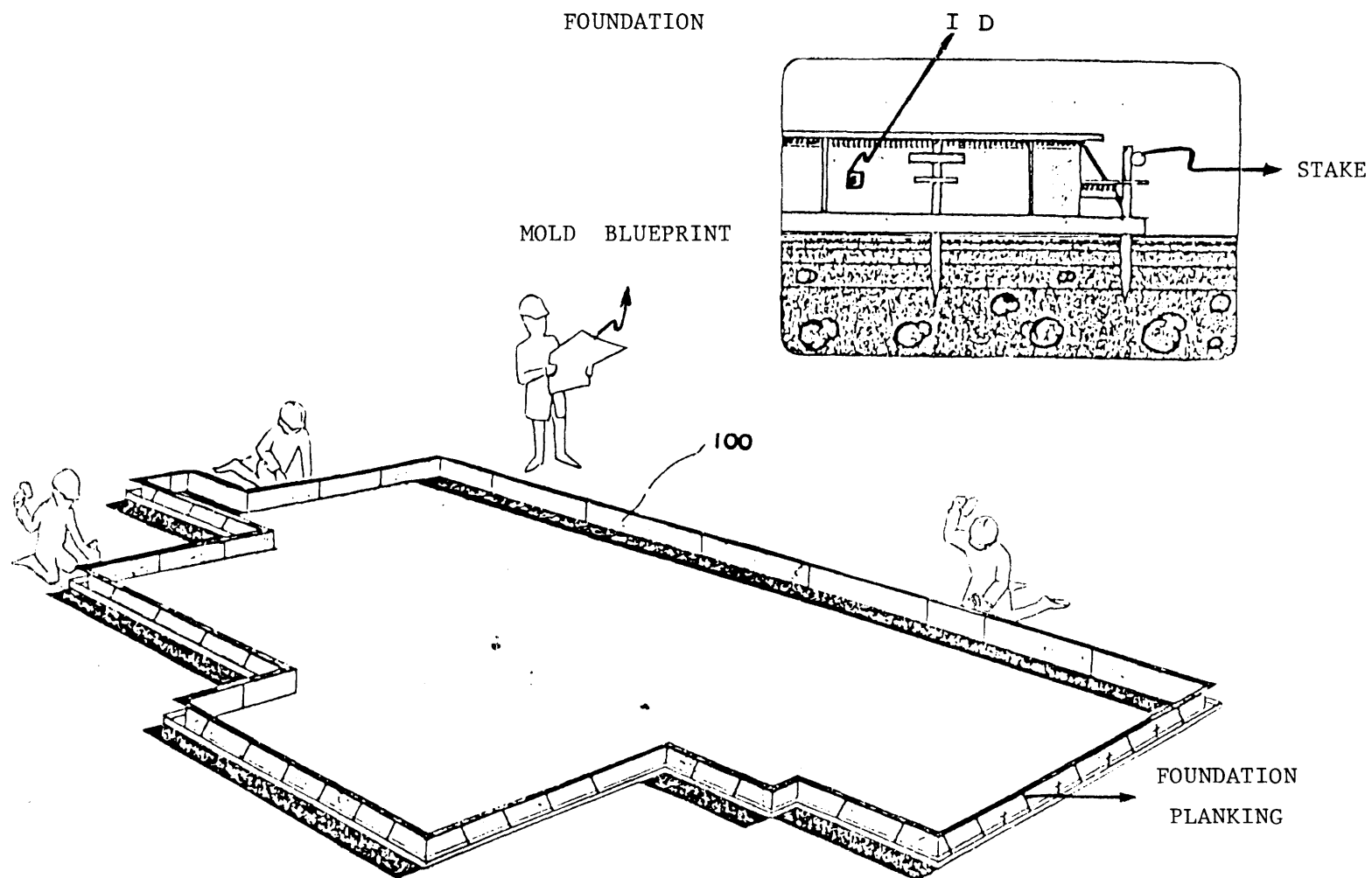
**FIG 1**

EXHIBIT 3

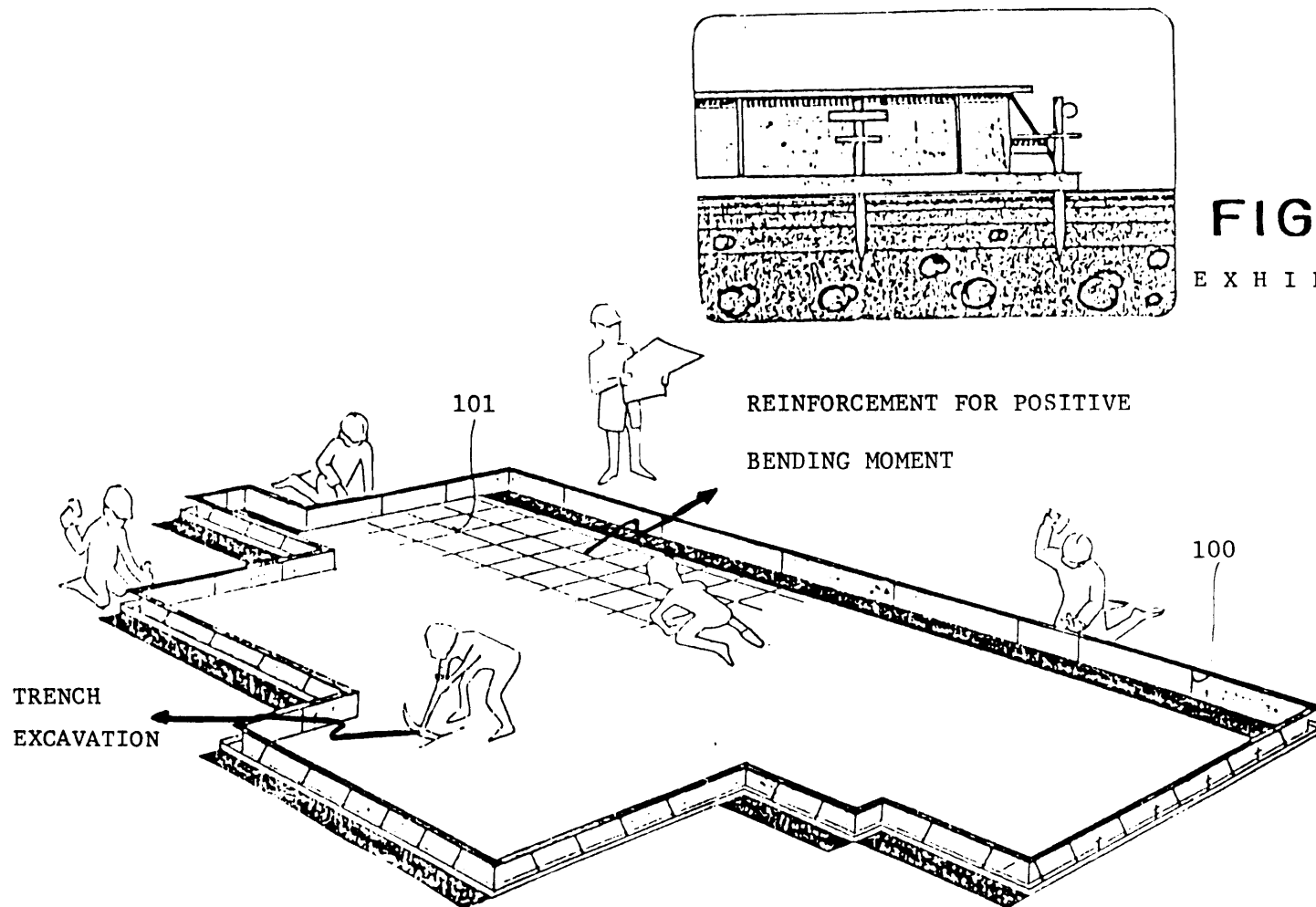
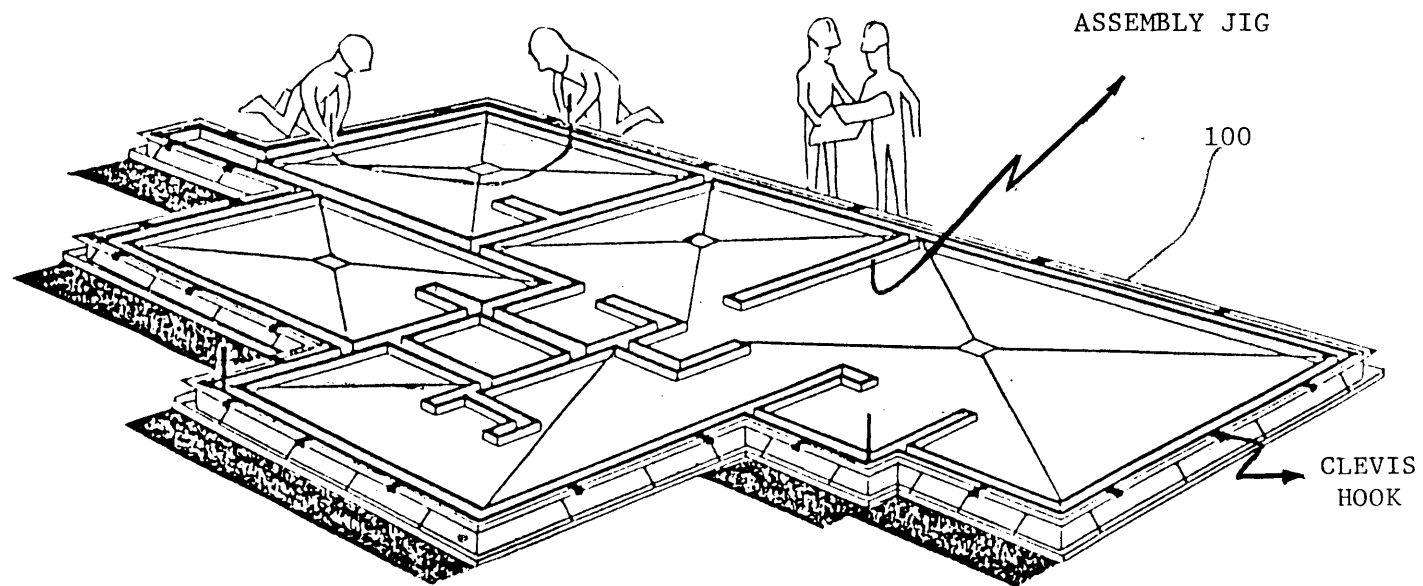


FIG 2

EXHIBIT 3



F I G 4

E X H I B I T 3

ASSEMBLY JIG

(DETAILS)

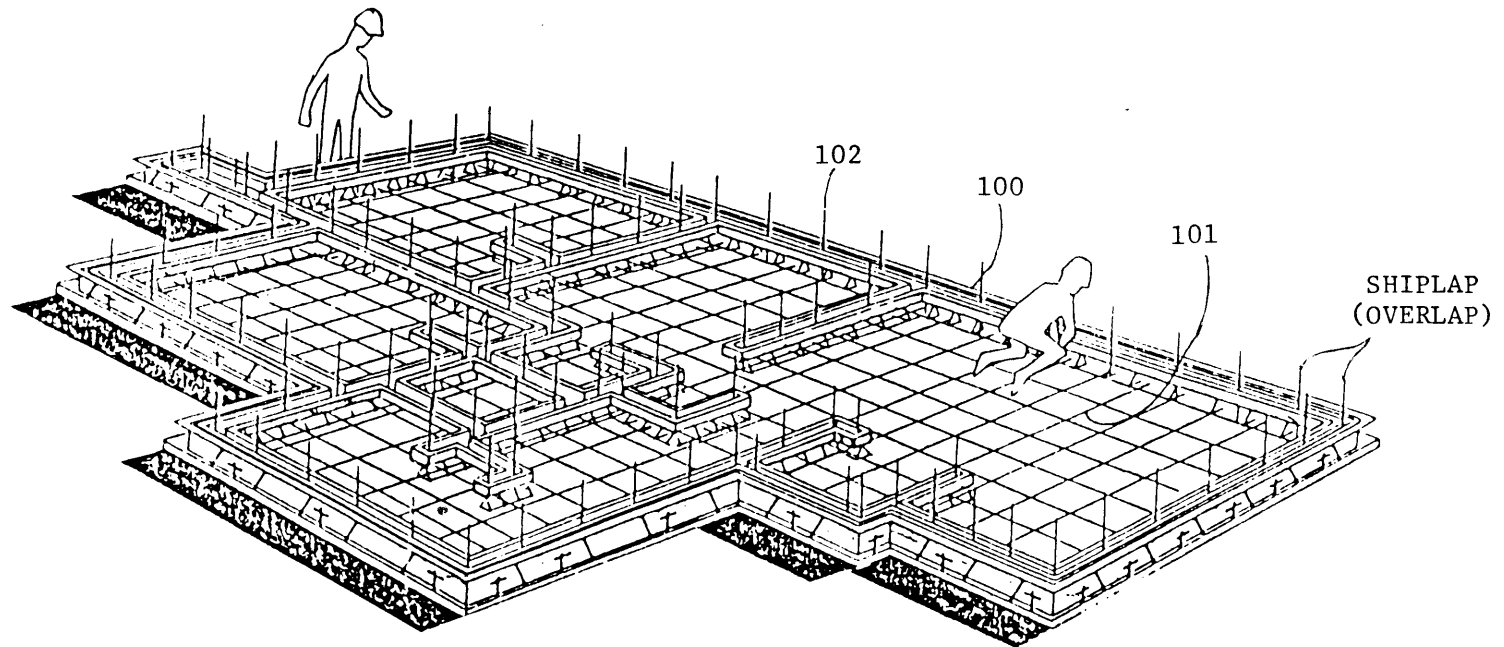


FIG 5

EXHIBIT 3

PLUMBING AND ELECTRIC SYSTEM DETAILS

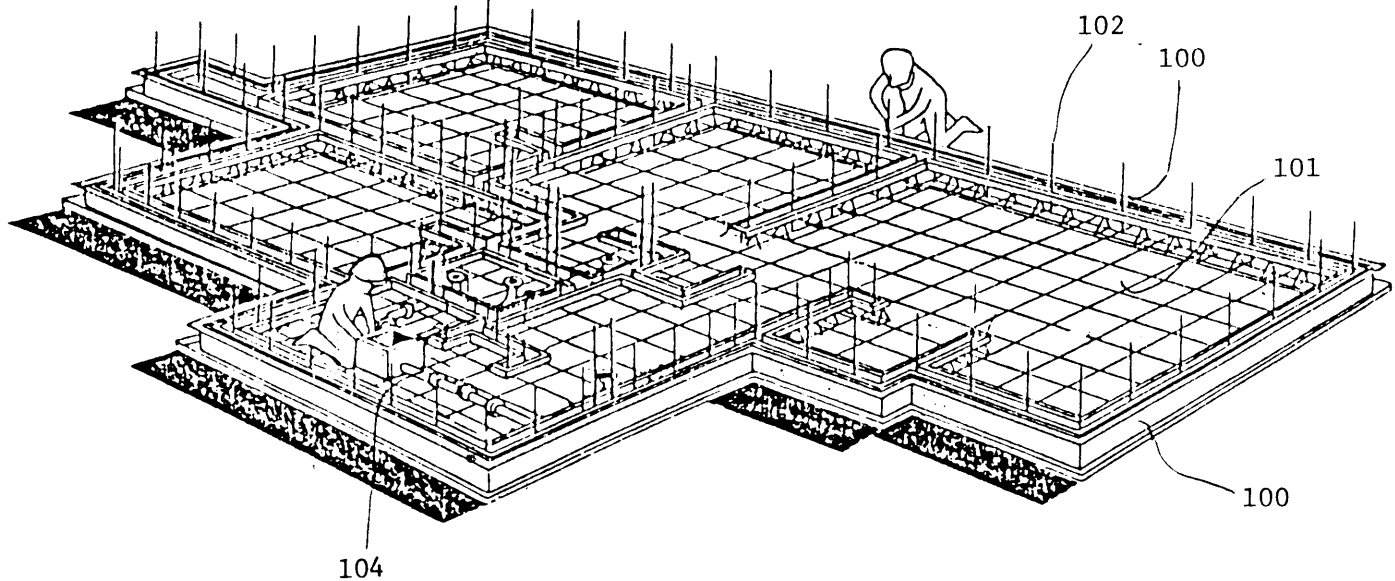


FIG 6

EXHIBIT 3

CAST AND LEVELING

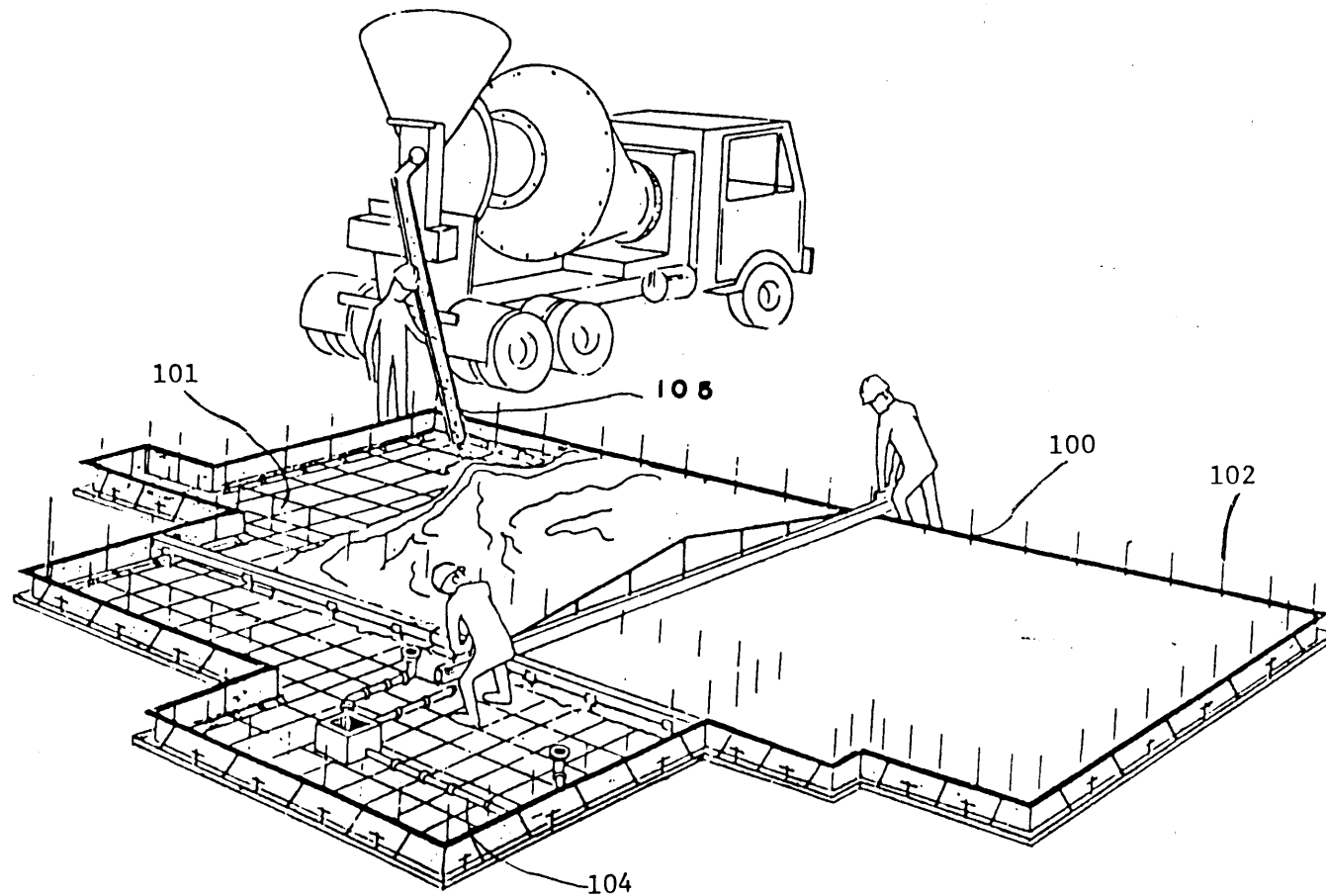


FIG 7

EXHIBIT 3

AFTER 3 HOURS OF FORGING :

" U s " WALLS GUIDES AND LUGS .

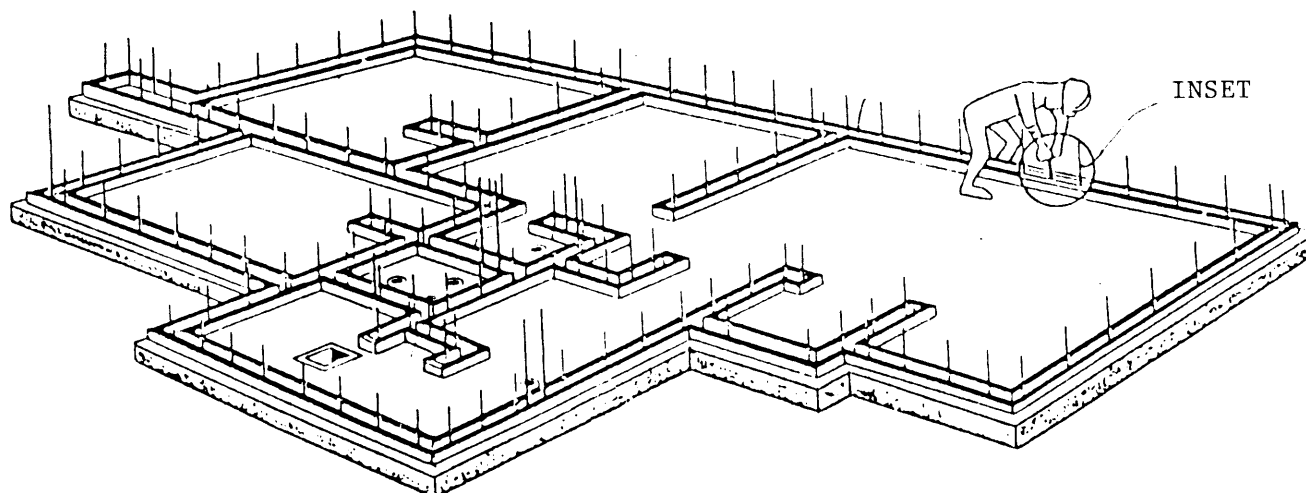
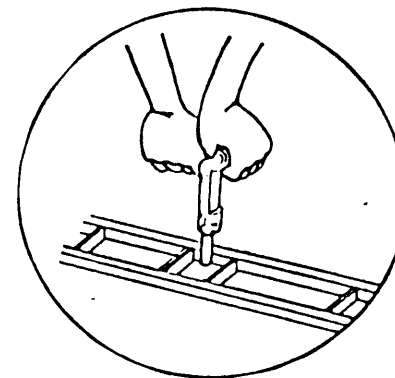
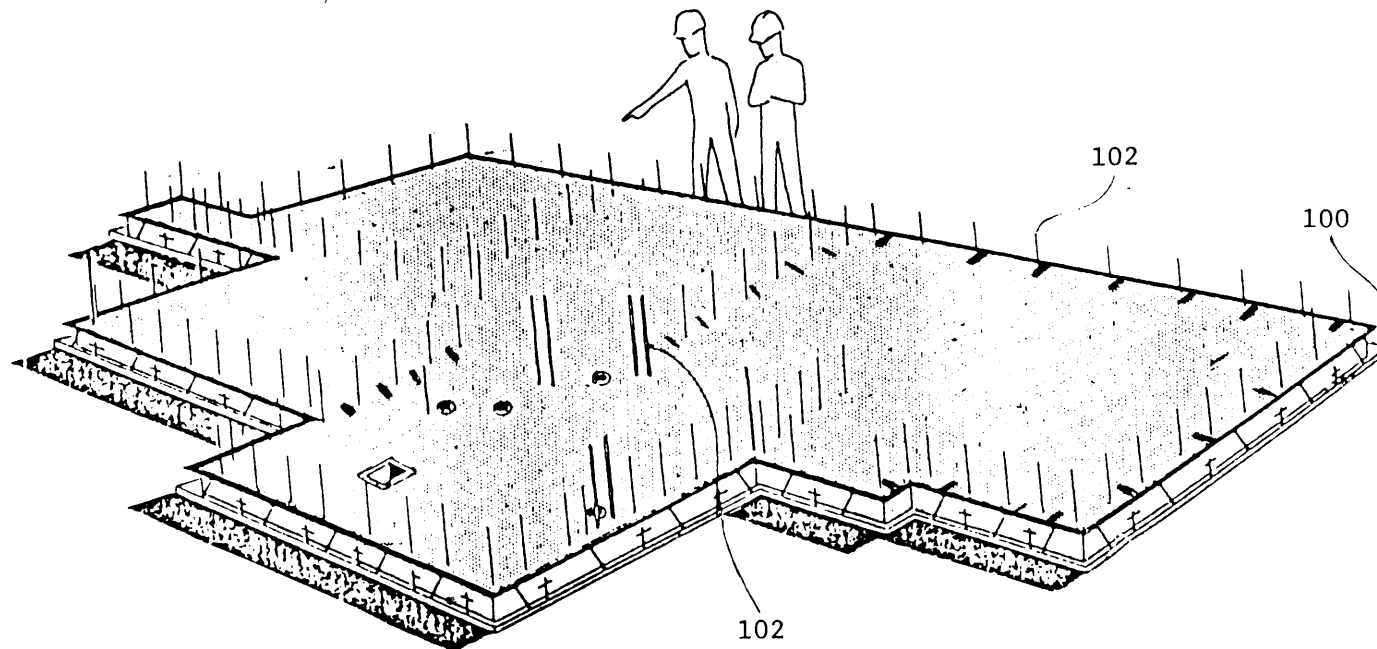


FIG 8

EXHIBIT 3

" U_s " DETAILS



CRITICAL REINFORCE

FIG 9

EXHIBIT 3

WALLS STEEL ERECTION

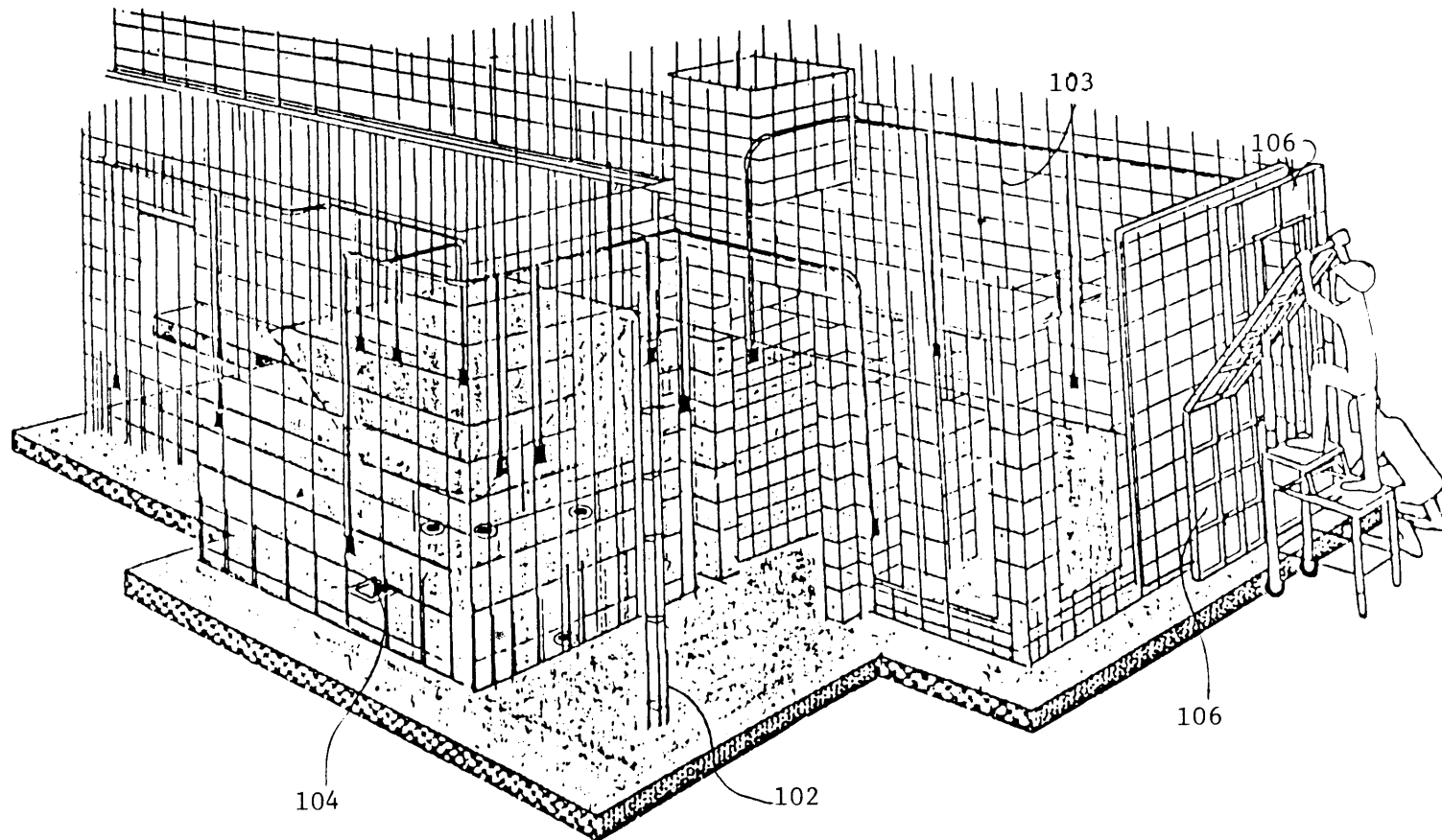


FIG 10

EXHIBIT 3

MOLD ASSEMBLED

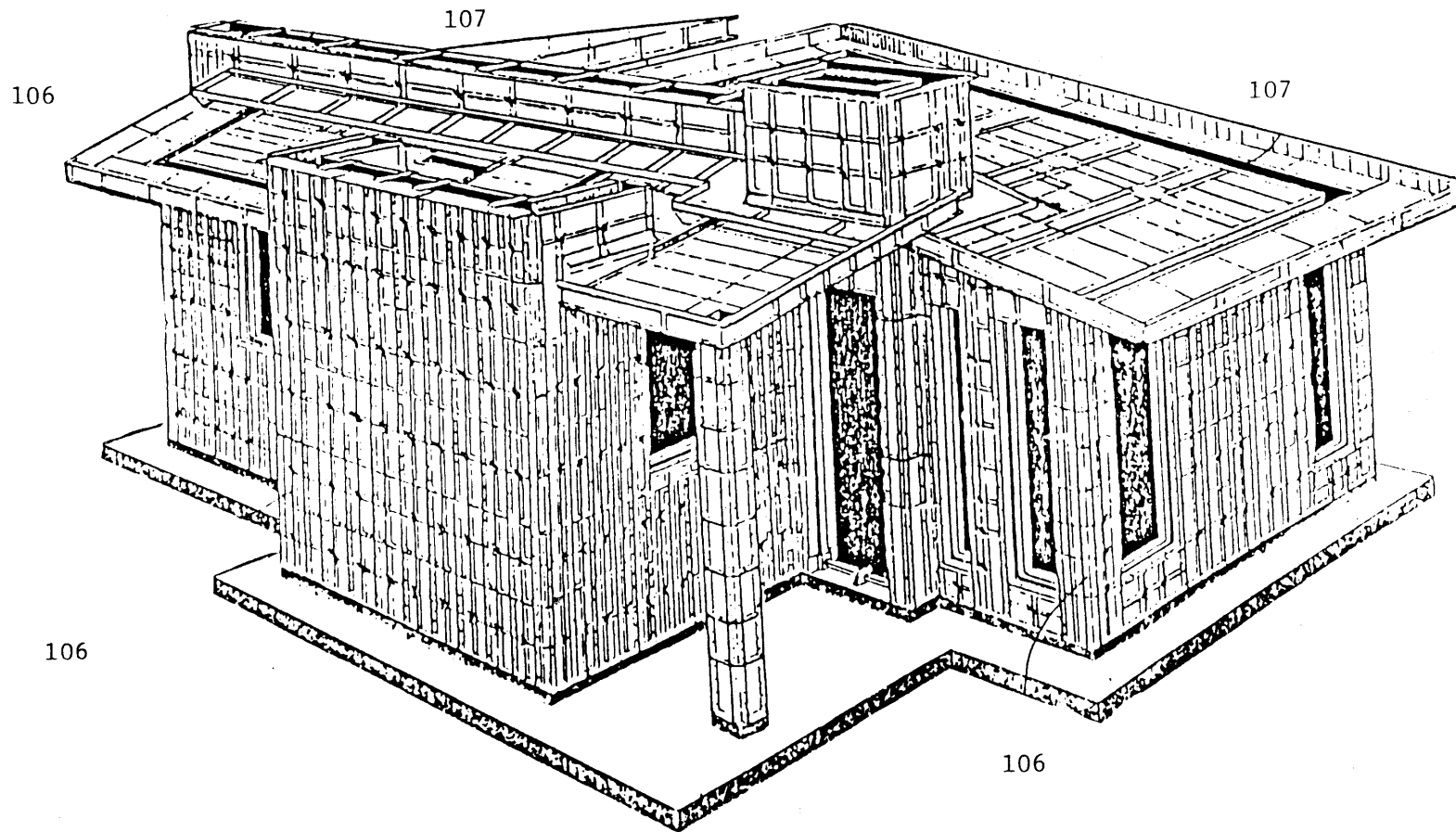


FIG II
EXHIBIT 3

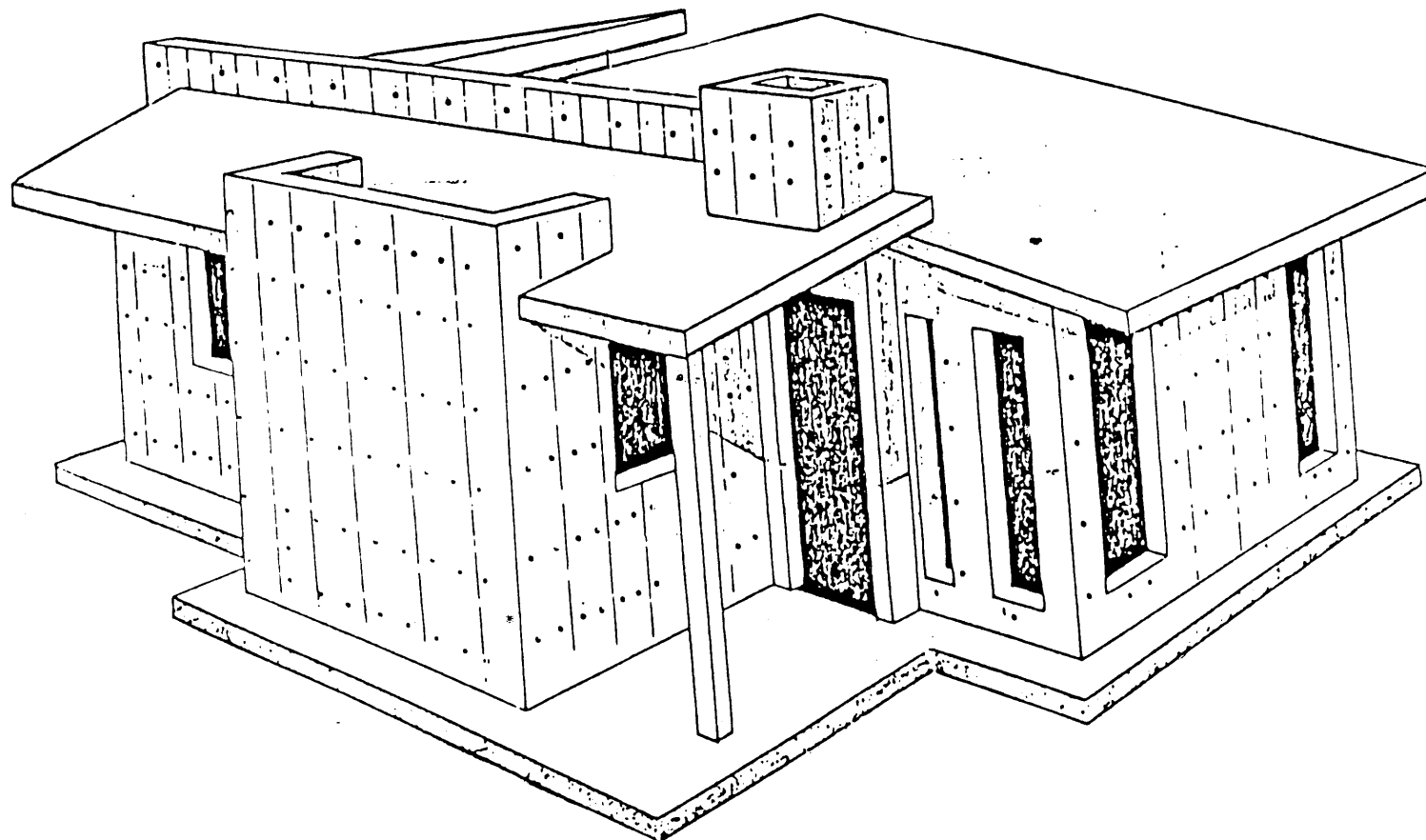


FIG 12

EXHIBIT 3

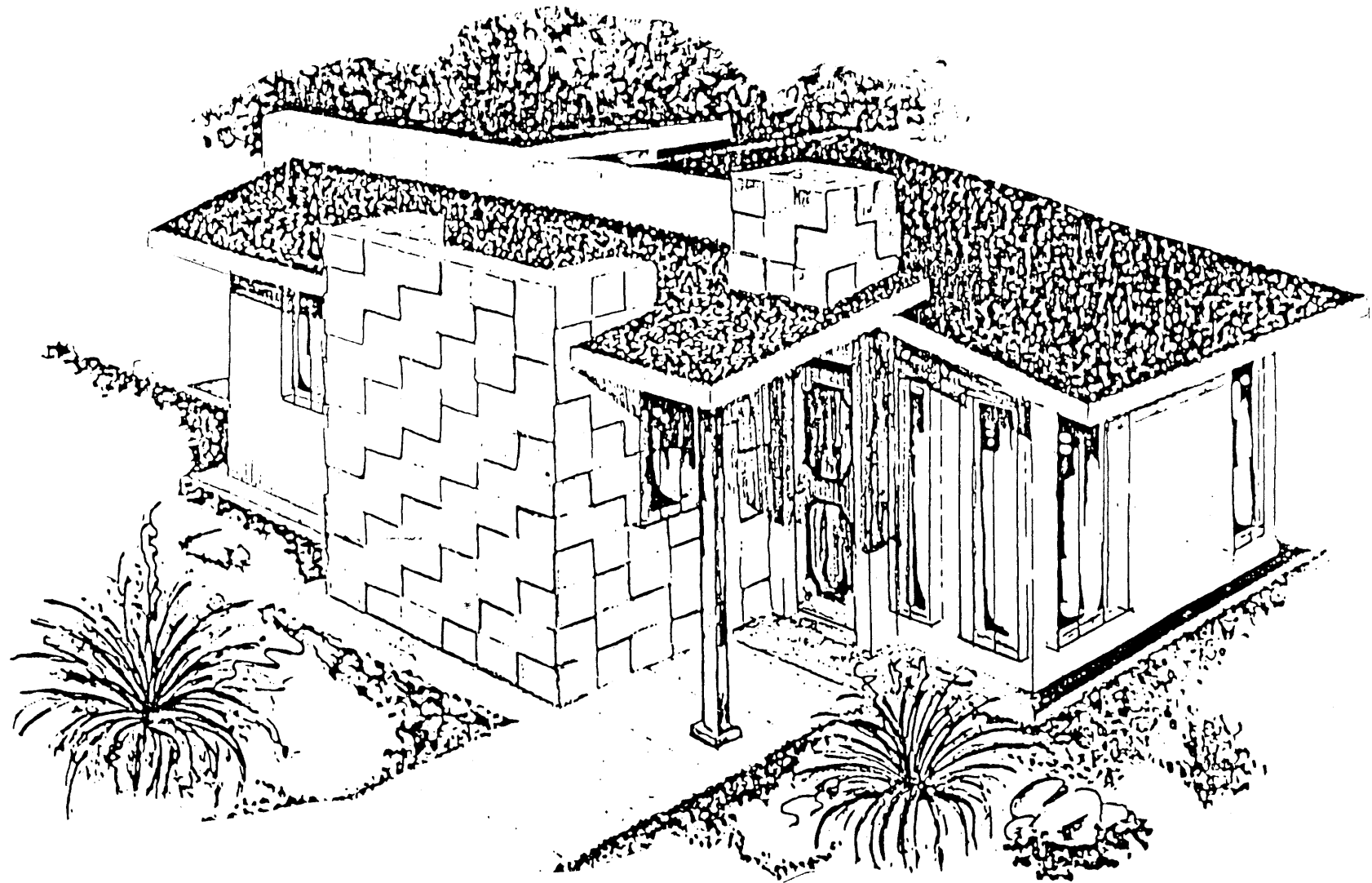


EXHIBIT 3 FIG 13

CHAPTER IV

POTENTIAL FOR COMPETITIVE ADVANTAGE THROUGH TECHNOLOGICAL INNOVATION IN CONSTRUCTION

This chapter presents a detailed investigation of the potential for technological development in one area of construction engineering: The automation of on site production processes. The actual state of the art in automated real-time data acquisition, process control, and robotics for large-scale field operations is addressed. This section also discusses categories of needs for advanced technologies on construction site operations and potential barriers to implementation. In addition, some applications of these automation technologies to industrialized systems for *in situ* casting are discussed.

4.1 THE POTENTIAL FOR NEW TECHNOLOGIES IN CONSTRUCTION:

ROBOTICS AND AUTOMATED DATA COLLECTION

Factory-based manufacturing industries have long been enjoying increasing economic, safety, and quality control benefits from automated data collection and from the process control of production operations; robotic applications are being incorporated as a logical extension of this trend. However, field-oriented industries like construction, with frequently reconfigured operations and often severe environmental conditions, have been slower to adopt automation technologies, and have scarcely been

touched by robotics, or automation in most countries. This section examines the reason for this, and suggest remedial technologies and research. The general purpose of this section is, to describe the needs and motivations for and potential of automation and robotics technologies; to review the state of art in selected areas of construction; to briefly define, examine and classify the various technologies; and to mention technical, economic, and institutional barriers to making the technologies an attractive goal and practical reality for industries like construction.

4.1.1 SPECIAL CHARACTERISTICS OF THE CONSTRUCTION PROCESS

Fast changing, field-based, project-oriented industries like construction are severely handicapped by their lack of accurate, timely and systematic technical, cost, and production data from ongoing operations.

Meanwhile, in other industries, technologies for automated data control have evolved that cannot only monitor the ongoing operation of manufacturing facilities and collect operational and passenger volume data from transit systems, but can monitor vehicle operations characteristics, transmit high-resolution video images, and capture results of instrumented biological, chemical, and geological experiments from unmanned vehicles sent to probe other planets. These rapid advances in other industries raise several questions. Why has not more of this technology filtered down to meet the needs of construction? Are there insurmountable technical problems in adapting these technologies to construction?

Or is there something about the structure or organization of the construction industry that makes construction companies resist change? Why have robots been slow to be incorporated into construction tasks?

The difficulties in introducing robots into construction provide a useful base study for learning some of the answers to these questions. Robot manufacturers gave several reasons for avoiding the market. Construction jobs are not always the same, so there is not a great deal of repeatability. Most construction jobs require a certain amount of on-site judgment, which a robot cannot provide. And there are a lot of uncontrolled environmental factors. If a robot is left out in the rain the company will lose a great deal of money. Robots work best where the environment is very structured.

Even though they are outsiders to construction, these robot manufacturers are able to identify the major technical and institutional issues that face project-oriented industries clearly. It is surprising, however, that robot manufacturers seem to be discouraged rather than challenged by the problems they describe. First, robots by nature are programmed and thus should be adaptable to changing environments, rather than restricted to the repeatable, very structured tasks prescribed by the present state of the art. Second, most construction jobs do indeed require more judgment than factory jobs, but is this not an area where the benefits of artificial intelligence and expert systems research might best emerge? Finally the environment is certainly a factor. But if robots cannot handle even a week of gentle rain, what would

happen during a winter on Alaska's North Slope; or in platform operations in the North Sea; or working 1000 feet underwater. How would they survive 120 F and sand storms in the Middle East, or working 100 stories up framing steel on a cold winter day? In many of these situations, robots could provide welcome relief from the safety and health problems that construction workers face every day. Construction machinery is manufactured to cope with such environments, so surely construction robots cope as well.

In any case the manufacturers are correct when they claim there are many problems to be solved, both basic and developmental, before automated data acquisition, robotics and process control technologies evolve to the point where they will play a significant role in the construction industry. Many of these problems can make exciting long-term basic research topics suitable for researchers.

4.1.2 PRESENT STATE OF THE ART

A vast amount of work has been done on automated real-time data acquisition, process control and robotics. Construction researchers must explore these fields and evaluate their technologies and research efforts for their potential relevance to construction needs and objectives. However, rather than attempt to review the vast general body of knowledge in data acquisition, automated process control and robotics, this section will focus primarily on related work in construction.

4.1.2.1 AUTOMATED DATA ACQUISITION APPLIED TO CONSTRUCTION

The first set of paragraphs below briefly review the following main areas that relate most closely to automated data acquisition: First, video data acquisition; second, computer-based data acquisition systems for field engineering operations; third, automated monitoring of construction quality control; fourth, automated monitoring of production rates and quantities for field operations; and fifth, recording and processing collected data.

Video Data Acquisition

The principal reference for applications of time-lapse photography, which preceded video data acquisition and operation analysis in construction, is "Methods Improvement for Construction Managers" [9. Parker and Oglesby]. Basically, these methods require an analyst to focus in detail upon an ongoing operation to understand relationships between tasks and resources, quantify activity durations, determine sources of delay, and indicate imbalances in the operation's design. Time-lapse film or videotaping has advantages in reducing the labor required to capture data, they capture more data simultaneously; they allow repeated viewing of the operation for different parameters, and they enable time compression. Industrialized construction firms, for example, can use time-lapse films to save time and labor during the intensive and repetitive process of mold assembly at the construction site.

Computer-Based Data Acquisition for Field Engineering Operations

This is an area where structural and geo-technical engineers have made considerable progress, but few have integrated their analysis and design-based instrumentation into real-total construction engineering decision-making. Some contractors, in Japan in particular, have put considerable emphasis on integration, and routinely instrument and monitor deep foundation excavations, offshore works, tunnels and similar structures.[11. Paulson].

Automated Monitoring of Construction Quality Control

An early integration of data acquisition and quality control involved concrete batch plants, particularly under the stringent requirements of nuclear power construction. Other recent examples are point-of-placement concrete quality testing and a continuous weld quality monitor developed by the Army Corps of Engineers at its Construction Engineering Research Laboratory in Champaign, Illinois.[1. Army Construction Engineering Research Laboratory]. The Corps have also used time-lapse photography to automatically record the coverage of compactors on earth-moving operations. Offshore platform construction projects, among others, have used various remote sensing devices to position piles and other parts of their structures. Lasers and other automated guidance technologies are used not only to increase excavation and grading production, but to improve quality. In the assembly process of a mold for

casting structures, at the site, spacers give the thickness of the walls, and props control the deflection of the structure. Frequently, spacers or props are misplaced or not properly tightened, and, the problem is often detected after the pour. Solutions as a result, can be very expensive. (Some times it is necessary to demolish the complete structure.) Remote sensing devices and laser technologies can be a potential solution to these problems. In general, however, this area is in its infancy in construction, and future research must draw much more from aerospace, defense, manufacturing and related higher technologies.

Automated Monitoring of Production Rates and Quantities

A number of mining operations have used sensors to count vehicles, such as trucks, to estimate production volumes, and even optionally to re-route trucks to idle loaders. The Japanese normally have automatic recorders attached to advanced soft-ground tunneling machines to record excavation volumes, advance rates, jack pressures, and other parameters to guide a "blind" tunneling operation. Computers controlling the complete batch plants mentioned previously also automatically record production and keep track of their stockpiles of cement and aggregates. A new and promising field application is monitoring grouting quality and production on a dam foundation.[3. Engineering New-Record] Factory-like production operations, such as pre-cast concrete plants, and paneling production for industrialized housing in Mexico and Colombia are also seeing increasing use of automated monitoring of

production. For most projects, however, there is no automating monitoring. Production rates are obtained manually, if at all, and often with questionable accuracy. The problem can be specially difficult in labor-intensive operations. The potential for automation is great, however, and, with improved information, more efficient planning and management of the field operations, should come.

Recording and Processing

Once operation data is collected, there are many purposes for which it can be used. Selected real-time data acquisition technologies can be interfaced to microcomputer-based software for automatic collection, storage, retrieval, preprocessing, statistical classification and conversion of collected data for analysis, design, and control decision-making. The construction industry has already had some experience with time-lapse and videotape cameras which record data on the cycle times of, the various elements in a process. They also provide qualitative evaluations and the relationships between these elements. These cameras are even used for quantitative studies, such as the development of computer-based simulation models.[4. Douglas],[10. Paulson].

4.1.2.2 AUTOMATED PROCESS CONTROL AND ROBOTICS

The next paragraphs briefly review the following main areas that relates most closely to automated process control and robotics in construction: First, On site-automated process control for fixed plants; second, partial of full automation of mobile equipment;

third, fixed-based of dimensionally constrained manipulators; fourth, mobile robots and androids; fifth, sensing and communications technologies; and sixth, automation for industrialized housing and building construction.

On site Automated Plant Control

The most progress today in automation for construction has been made in the control of temporary on-site plants for batching concrete, bending reinforcing steel, and making pre-cast concrete elements. For example, in batch plants for higher volume, high-quality concrete production, such as those for nuclear power stations, a computer controls the selection, transport, weighing, charging and mixing of cement, sand aggregates, water and admixtures for a batch that meets specified design criteria for a specific structural component, and simultaneously handles administrative reporting for delivery, quality and cost control. A larger fraction of construction processes can benefit from automated process control of this type, to the extent that more construction processes and components can be redesigned for prefabrication in plant-type facilities, whether on-site or off-site.

Automation of Mobile Equipment

Most major construction equipment manufacturers are experimenting with and even producing some machines that include on-board microprocessors for monitoring performance, maximizing engine power and fuel economy, optimizing gear shifts,

keeping loads within safe tolerances, etc. These applications are beneficial, but are fairly limited relative to the real potential for the partial or fully automated control of machines as whole units in the overall production process.

More dramatic is the application of automated excavation grade control using laser surveying equipment (see several brochures on laser-controlled excavation and grading, printed by Spectra-Physics, Inc., of Mountain View, California) combined with electrohydraulic feedback control systems mounted on bulldozers, motor graders, scrapers, etc. In applications such as highway grading, constructing large parking lots, and canals, these techniques have reduced costs in some cases by over 80% and improved quality (e.g., by achieving sub-grade thickness tolerances of 2% versus 10-20% otherwise achieved on normal work). They also permit the substitution of lower costing machines (e.g., small bulldozers for motorgraders) and lower-skilled operators, while giving quality improvements. Japan's Komatsu Tractor Company has also done related work in remote-controlled amphibious and submersible bulldozers for work in coastal areas and hazardous environments [2. Asano.] (see also brochures on amphibious, underwater and remote controlled bulldozer applications, printed by Komatsu, Ltd., of Tokyo, Japan). Japanese firms are also implementing full face tunneling machines that incorporate a variety of sensing and control mechanisms to optimize tunnel excavation.

The next step, moving to more fully programmed automation, is much more difficult. At this stage, the machines become robots with some limited programmed intelligence for self-guidance and control over complex routes and surfaces. They make decisions on what to do about obstacles, and respond to unanticipated changes.

Spatially-Constrained Manipulators

Much publicity about robotics in manufacturing industries currently centers on multi-jointed robot arm and hand mechanisms attached to a fixed base or platform, such as a gantry, that covers a clearly defined and limited area. With such a well-prescribed three dimensional frame of reference, they can be programmed for operations requiring high precision.

Although the construction environment is often loosely constrained and frequently reconfigured, there is still considerable potential for this type of automation. The processes can be redesigned to fit the tools, and the tools can evolve to handle a wider variety of processes more flexibly. Carnegie-Mellon University researchers have experimented with such a robot arm for unit-masonry construction [7. Kraker.]. Japan's Shimizu Construction Company has mounted such an arm on a mobile platform and is using it to apply sprayed insulation in building construction.[6. Engineering News-Record.]. In Finland, a very large robot arm has been used for harvesting trees for wood pulp. Other possible applications of such robots are in tunnels where operations

(e.g., liner erection) are highly repetitive and fit into well-defined geometric constraints.

Mobile Robots and Androids

Apart from Shimizu's platform-mounted robot arm mentioned in the foregoing, few attempts have been made to develop and apply mobile, walking-type robots and androids, even in manufacturing, let alone construction. However, owing to the nature of project sites, such devices might have even greater potential in construction than in plant-based manufacturing. A number of possibilities have been explored, including a walking spider-like robot to assist in the clean up at the Three Mile Island nuclear plant, others for the assembly of space platforms and work on other planets. However there is not real prototype yet for a general-purpose robot flexible enough to be a general utility tool on field projects. This is an attractive area for research.

Sensing and Communication Technologies

For years various kinds of instruments have been installed before or during construction operations for technical or safety reasons. Particularly good examples are geo-technical and structural instruments for monitoring tunnel and foundation excavations. A new and promising application is monitoring grouting operations for a dam foundation. The electronic revolution has brought rapid advances in surveying equipment that measures distances, angles and volumes. Mobile radio communications have

also been involved in construction projects, at least since the 1940s, not only among project engineers and supervisors, but are used by foremen directing equipment operators, operators calling for fuel or repair assistance, signal men talking to crane operators, etc. In other words, there is already considerable experience with equipment and technologies that could support machine data acquisition and control functions. Little has been done, however, to take advantage of the existing infrastructure for automated process control purposes.

Automation for Industrialized Housing Construction

As mentioned at the end of chapter three, industrialized construction systems for housing are relatively new in the market. They represent big savings in time and cost in large housing projects; however, further research could double these savings if software applications are developed to convert the architectural blueprints of the house into their technical equivalents. This new technique will not only save the cost and time of architects but will also reduce risk and time in the manufacturing process of equipment. Many other innovations can be made in these systems of construction such as automated monitoring of assembling quality control, data acquisition in the mean of reducing unnecessary steps in the assembly process, and even the reduction of the high intensive labor that is needed at the construction site to assemble and to carry the equipment. This maybe long term goal could be achieved by developing robots able to detect the sequence of the

panels, to remove, and to assemble them where needed; but it is necessary that people in production with "know-how" and talented R&D engineers be prepared to meet the challenge of these industrialized construction housing technologies.

4.2 POTENTIAL APPLICATIONS OF AUTOMATED DATA AND ROBOTICS TO CONSTRUCTION

Proceeding from the review of the state of the art and the selected examples that have been presented, this section provides criteria and suggest categories for a more general classification of potential applications of automation in construction.

In order for automated real-time data acquisition, process control and robotics to begin having a greater impact in construction, it will be necessary to acquire a sound understanding of current and projected technological developments in several discipline areas. The development of a useful classification system would help researchers define appropriate topics and objectives, and guide industry and government in developing effective, coordinated long-term programs of research. Possible general parameters for classifications include the engineering and scientific disciplines needed for further research; their potential areas for application on various capital -and labor- intensive large-scale remote field operations; their present and potential state of advancement.

4.2.1 POTENTIAL APPLICATION OF AUTOMATED DATA ACQUISITION

The types of data that could be considered for automated real-time monitoring and collection include: first, engineering parameters during construction, such as soil displacement toward a foundation or tunnel excavation; alignment and dimensional tolerances for structural members; subgrade thickness; and construction live and dead loads on partially completed structures. Second, quality control monitoring and correction; such as continuous weld quality monitoring; soil compaction; concrete composition and strength; bolt tightness; structural member alignment and deflection; water and air quality; and safety standards. Most quality control procedures are done after an activity is completed. When the activity fails, consequential delays, interruptions and expensive rework are needed. Immediate feedback would enable remedial action to be taken while production was under way, and thus minimize the consequences of defects. Third, production rates and quantities, with measures of associated resource consumption and productivity. Much such data is collected now through manual measurement (surveying) techniques and through administrative procedures like labor and equipment time cards. The manual measurement can be too expensive to justify the detailed collection of quantities, and administrative procedures are notoriously vulnerable to delays, inaccurate recording and even falsification.

4.2.2 POTENTIAL APPLICATIONS OF AUTOMATED PROCESS CONTROL AND ROBOTICS

Among the types of automated process control and robotics applications and technologies to be considered are: first, on-site automated process control for fixed plants, such as concrete batch plants, reinforcing bar cutting and bending, pipe fabrication, carpentry shops, pre-cast concrete element fabrication, and aggregate crushing and screening plants. This type of application would be the most similar to factory automation, a high-turnover and often inadequately trained labor force, provisions for severe environmental conditions, and adaptability to a frequently changing product mix. Considerable progress has already been made by industry in some of these areas. Second, partial or full automation of mobile construction equipment, including trucks ranging from light utility vehicles to large off-highway haulers; excavating and grading equipment such as scrapers, loaders, shovels, compactors and graders; materials hoisting equipment such as cranes and forklifts; and a wide range of specialty equipment such as paving machines, tunnel boring machines, construction railways, cableways and pipelayers. There has been some progress in a few of these equipment, specially in industrialized countries. Third, robot arm manipulators. These are among the basic components of factory automation, and have obvious applications in areas such as the ones explained in the first application in the foregoing. By relocating such manipulators into traditional field positions, the scope and economic potential of applications could be huge. Fourth, mobile

robots and androids, including those with wheel, track type and walking transporters. Although such robots often contain one or more manipulating arms like their fixed-base counterparts, they are distinguished by a high degree of mobility, normally unconstrained by tracks, guidewires or other fixed references; they have a wider variety of sensors to cope with changing and less predictable environment; they are often battery powered to move without external power sources; and they typically have more onboard computer power to allow a greater measure of independent programmed analyses of and responses to their environment and tasks. Androids, robot devices that attempt to approximate the physical form and some functions of humans, are included so that the term "robotics" can apply to a wider range of mobile devices, without regard to their physical shape or functionality.

4.3 NEED FOR AND BARRIERS TO IMPLEMENTATION

In contemplating the future of automation and robotics, it will be necessary to define, classify, and determine general priorities of needs for and barriers to the implementation of automated data acquisition, process control and robotics in several areas. Categories could include large versus small projects, labor-intensive versus capital intensive operations, industry sectors (buildings, civil works, process plants, housing), phases and technologies within projects (side work, foundations, structural, piping, electrical, etc.), and

types of firms such as design-construction, general contractor, specialty contractor, etc.

It is also important to consider potential industry barriers. In a field like automated process control and robotics, there are certainly some social and economic as well as technical barriers that must be identified and overcome if research efforts are to succeed eventually in development and implementation. Researchers who proceed with such studies should be made aware of these barriers. In brief, the obstacles to technological advances are many in construction, and relate more to institutional problems, such as company and process fragmentation, risk and liability, codes and standards. Through anticipation and careful planning, the barriers can be overcome as they have been to some degree in some industrialized countries.

CHAPTER V

PREPARING THE FIRM TO USE INDUSTRIALIZED CONSTRUCTION PROCESS AS A SOURCE OF COMPETITIVE ADVANTAGE: A Case Study of Innovation in Industrialized Housing in Colombia

This chapter discusses the fundamental issues involved in competitive advantages of technological development in construction firms. A framework of the process to gain and sustain competitiveness with industrialized systems of construction for *in situ* casting is proposed and the role of competition in the technological development of firms is discussed. The expansibility to which findings may be unique to industrialized construction systems or of more general applicability are analyzed.

5.1 CASE STUDY: CONSTRUCTORA LA SABANA. Co

In the third quarter of 1980, the Housing Construction Industry in Colombia was undergoing significant change. New competitors were entering with new construction systems and new technologies, and traditional competitors were beginning to feel the effects. The construction division of La Sabana company was no exception, and the profits of 1980, for this long established company were proving to be disappointing.

At the beginning of 1981, Mr. Carlos Sanchez, co-founder of the company, was on his way to Mexico City with his family. Two issues were on his agenda: To study the impact of a new technology, "Meccano Construction System", upon the Mexican construction market and to make contacts and discuss the possibility of acquiring the technology and the possible implementation of the manufacturing process in Colombia.

5.1.1 COLOMBIAN CONSTRUCTION INDUSTRY

For many years, the construction industry has been the largest industry and employer in Colombia. In 1981, total new construction plans were valued at nearly 20% of the gross national product. More than 1.2 million construction workers and 1 million workers in related construction services depended on this core industry for their livelihood.

Despite its importance in the Colombian economy, the industry has been slow to invest in innovative methods, materials, and processes. In 1981, industry R&D expenditures averaged less than 0.01% of sales.

Significant barriers for innovation in the Colombian construction industry were, the fragmented structure of the industry and the absence of foreign competition. These were responsible, in part, for the continued use of traditional construction methods. Low margins and fierce domestic competition precluded the kind of investment needed to develop new methods

or materials. Liability concerns further exacerbated an industry preference for proven construction methods, increasing the risk of working with new materials or processes. Constructability was virtually ignored until designs were complete, making changes both time-consuming and costly.

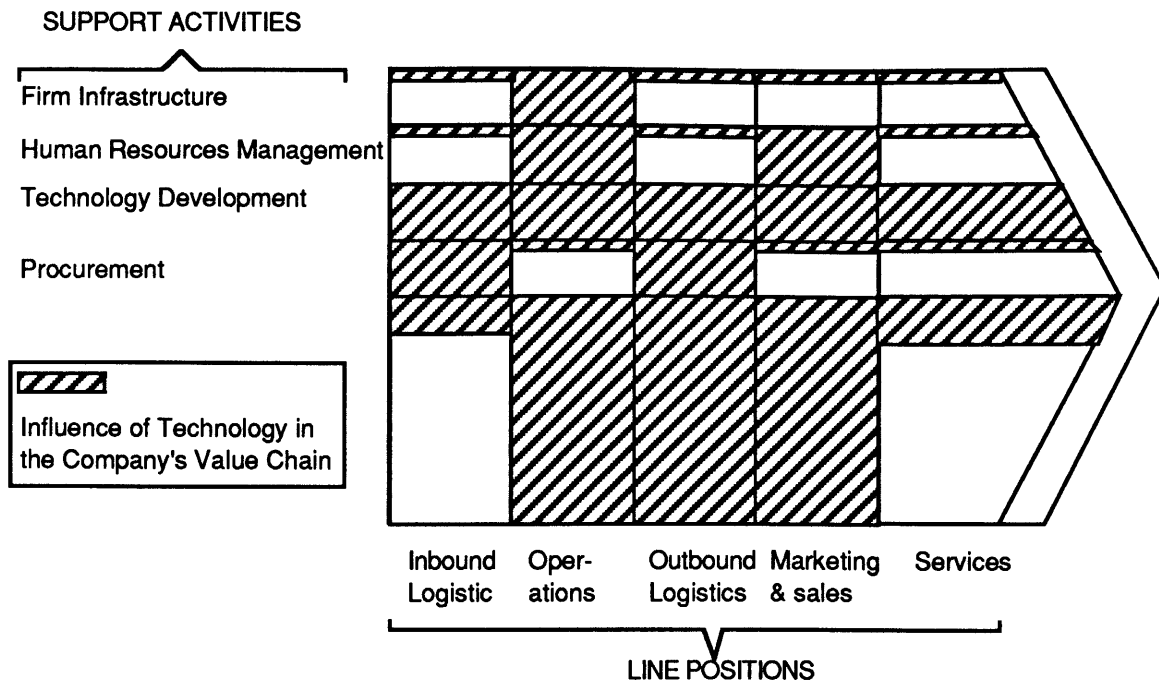
Industrialized systems and regular construction still compete in the open Civil Engineering market in Colombia; however, as a result of technical and cost advantages, some constructors have found industrialized systems in the construction industry very attractive.

5.1.2 . COMPANY VALUE CHAIN

Mr. Sanchez is interested in the acquisition of the Meccano system (see description of the Meccano technology in section 3.5.4). He knows that the implementation of this new technology will require important changes in the value chain of his organization. New departments and new personnel with high mechanical capabilities, as well as new fixed costs, will be important issues to take into account in the company's long-term strategy. Additionally, competitors in the construction industry will be attentive to his movements.

The following figure highlights the important changes in the value chain of the company after the implementation of the new technology.

FIGURE 5.1. LA SABANA CONSTRUCTION COMPANY VALUE CHAIN



In order to succeed, as it is shown above, magnificent linkages between R&D would be needed. Know-how would be necessary throughout the complete organization, even though, some activities do not have to deal with complicated technological tasks. Technology development in this company, for example, would affect all organization activities through the efforts to improve procedures in office automation for the accounting department, efforts to improve sales and services with the new construction system, efforts in selecting better materials for the production process and efforts to improve the technology itself.

5.1.2.1 FIRM INFRASTRUCTURE

La Sabana infrastructure will need new planning, finance, accounting, and management systems. The primary risk of change is the possibility of "overhead", however such a change could be a powerful source of competitive advantage if the linkages between activities in the value chain are concentrated in demonstrating to developers and owners the advantages of the system in their own value chain. The advantages in construction costs for large projects, advantages in time saving in the construction process, the advantages in construction management, and the advantage of not affecting owners behavior will abolish the risk of overhead. Protecting the technology with patents, licenses and copyrights would be among the issues that infrastructure management would take into account to gain advantage with this technology. Similarly, these top managers would play a vital role in dealing with developers and clients. If a technically trained sales force is not available to explain the performance advantage to the buyer, and if the manufacturing process does not contain adequate provisions for quality control, the differentiation in product performance will lose much of its impact.

5.1.2.2 FIRM HUMAN RESOURCE MANAGEMENT

The chain of the company in the new business will also need to be changed with respect to the human resource management support group. With the introduction of the new concept of construction, the retraining of civil engineers, mechanical engineers

and architects would be needed. Even though the system is able to accommodate any architectural design, the transformation of architectural blueprints to "mold, design and assembly" blueprints, requires special skills and well-trained architects and draftsmen. Project Managers in charge of the construction process would have to be able to deal with mechanical and design problems at the construction site. Mr. Sanchez is aware that his company would need to have foreign instructors and recruiters during the implementation of this technology in Colombia. The human resource management group at La Sabana Co. can contribute greatly to obtaining a competitive advantage if it can train and motivate employees, who would be prepared, after a certain period of time, to manage the new technology without foreign support.

Human Resource Management will also be in charge of recruiting R&D personnel. Most important would be the engagement of creative and innovative engineers in the firm. These engineers would represent the fundamental support of technology development and research, to compete with technical basis, when followers or companies with other industrialized technologies attack the market. People with know-how are particularly important in a low cost strategy where the R&D program should include a heavy dose of projects designed to lower costs in all value activities that represent a significant fraction of the company's total costs. This is particularly important because what clients want is projects within time, budget, and specification level, regardless of special capabilities or elegance of the technology. Even though the

implementation of a new technology inevitably affects the client's value chain, the issue of technology for improvement is particularly important in the construction firm's value chain .

5.1.2.3 FIRM TECHNOLOGY DEVELOPMENT

One of the most important areas of change that La Sabana's chain would have to have is in technology development. By contrast with traditional procedures of most companies in the construction industry, La Sabana Co. would have to use R&D as the tool to become competitive in big housing projects in the construction market. The array of technologies to be employed in this firm combines a number of different sub-technologies, such as metallurgy, mechanics, construction management, design technology, etc. Technology development for construction projects may take many forms, from basic research and mold design, to process equipment design and servicing procedures. Research in software applications to convert the architectural blueprints into their technical equivalents, and further research in robotic for assembly and disassembly of panels, for example, could be among the goals that R&D may take in order to achieve cost and differentiation advantages among competitors with other industrialized systems. In addition, the acquisition of the Meccano technology would open doors for future research in automated data acquisition, not only in the manufacturing process of molds, but also for construction operations. By establishing strong links with designers to improve construction, mechanical engineers to

automate production, and further research to automate construction, the company would gain advantage, in a long term strategy, based on improved performance of the technology in the different projects. Cost advantage and differentiation are the main objectives that Mr. Sanchez wants to achieve with the acquisition of the Meccano technology. The key factor in reaching these objectives would be the linkage between the company's current activities and future technological development or research.

5.1.2.4 FIRM PROCUREMENT

Procurement would also require important changes in La Sabana's chain. Acquisition of machinery, solder, steel sheets, steel pipes, steel angles, etc, would involve specialized people. Steel prices over a long period, would also become the most important cost for the company if the production of equipment or molds increases rapidly. Meccano system in Mexico, for example, is producing from ten to fifteen different molds every month with a mean of thirty tons of steel each. Improved purchasing practices could strongly affect the cost and quality of purchased inputs; as could other activities associated with receiving and using the inputs. To achieve success, the Meccano system requires high quality steel in many shapes as a raw material and several tons of resistance brazing of high purity for mold production.

5.1.2.5 COMPANY LINE POSITION ACTIVITIES

The company network for marketing sales and services for current construction would be important for the new businesses. Therefore, special training in the system capabilities, prices and services, as well as, computer-based tools that offer a clear potential to improve the efficiency of operations would be needed. The company would also need to have new inbound operations not only in raw material storage, weld quality control and material handling, but also in molds storage when they are returned after project completion for maintenance and future reshipping. Likewise, new outbound activities, such as shipping and reshipping of molds, inventories, and material handling from the factory to the construction site would also need to be incorporated into the new company organization.

5.1.3 THE FIVE FORCES THAT DRIVE INDUSTRY COMPETITION

Mr. Sanchez believes that the implementation of the Meccano technology would be worthwhile despite the changes in the company's value chain. The segment of the industry in which the system would operate is in the construction of a series of houses or apartment buildings. He knows that his firm could not set technology strategy without considering the five forces driving industry competition and their structural impacts in this segment of the construction industry.

5.1.3.1 ENTRY BARRIERS

The implementation of Meccano in the Colombian market would be a powerful determinant of entry barriers. La Sabana would be protected by high entry barriers due to the high cost of the technology and the possession of the rights. This would imply that the company would face competitors' attempts to create new channels or technologies other than invasions of the existing ones. To face these competitors, the company's R&D must be attentive to improving the technology performance and in taking advantage of the experience, and learning curve results from such improvements. Future implementation of automation and data acquisition technologies in the construction process of projects, and implementation of automated monitoring of quality control at the construction site and in the factory could also help to deter new competitors.

5.1.3.2 BUYERS

One of the most important objectives that the new technology would achieve is the bargaining relationship between La Sabana Construction Co. and its buyers. The influence of reducing costs and time and increasing quality in the process of construction would help to establish strong links with owners to develop improved technologies based on user needs. This would give two advantages: increased performance based on new technology and improved fit with the customer's needs. In effect, the Meccano system would give better service, for many reasons. Owners could have their

project finished in less than half of the time needed to finish the project following regular construction procedures, the quality will be better not only because the houses or apartments meet the most demanding construction regulations, but also because they can be fire and earthquake warranted. Performance is also improved because, after a unit is finished no further maintenance is needed for a long period of time. In few words, this system of construction would give more service, quality and performance "for the money". This is what customers always want.

5.1.3.3 SUPPLIERS

Suppliers will also play a special role in La Sabana's long term strategy. The new technology would force the company to purchase from new, more powerful suppliers. Hundreds of tons of steel in additional shapes and high performance specifications will be needed for the production process and maintenance of the equipment. In Mexico, for example, Meccano has produced molds continuously for more than ten years to absorb local demand without stopping production, and it is not uncommon to have three shifts of production some months of the year. Through the learning curve the R&D team is responsible for lowering costs, finding new materials and substituting inputs to be used in the new product. Creating in-house knowledge of supplier technology would also reduce dependence on suppliers.

5.1.3.4 PRODUCT SUBSTITUTES

The Meccano system seems to be a good substitute for Con-Tech, Lift ,Tunnel and regular construction of large housing projects, not only in product, but also in process (see Exhibits 1, 2 and 3, chapter III). The efficiency of this method can help La Sabana to grow. However, To sustain this growth the company has to be prepared to compete with the emergence of other new technologies.

A good policy for La Sabana Co. would be the development of capabilities to switch or combine steel and aluminum technologies for equipment production. In so doing, with the development of aluminum technology in Colombia, the company would be ready to compete with Fast-Tech construction systems. Additionally, the size and reputation of La Sabana would enable it to use their former marketing and service networks for the introduction of the improved technology far in advance of other companies attacks on the market with Fast-Tech technology.

Mr. Sanchez believes that buyers would perceive the benefits of Meccano construction as a substitute system of other systems technology and of regular construction for the following reasons: Primarily, lower costs would be reflected in the bid or negotiation phase. Secondly, the Meccano system would show the direct advantages of time saving and quality during the construction process itself. Thirdly, the advantages of the technology would raise performance from the beginning of the construction. Finally, the technology would not affect the buyers' or developers' behavior or patterns, and the credibility of the Meccano system's benefit will be

easy to assess. In other words, buyers may fully understand the impact of this new method of construction in their own companies' value chain.

5.1.3.5 COMPETITORS

The acquisition of Meccano would also alter the "force" of rivalry among existing competitors in Colombia. The construction of a series of housing projects would be affected by introducing this revolutionary construction system, and the impact of the Meccano technology on rivalry would be through its effect on creating high exit barriers to competitors. Companies with other industrialized technologies and expensive equipment would not be able to exit the market due to the highly specialized assets with low liquidation values. These companies would therefore not leave the business and would try to compete even with low earnings .

5.1.4 ACQUISITION OF RIGHTS

The introduction of Meccano in Colombia's construction market would imply high fixed costs and a great deal of time that would need to be protected. A very important step in the strategy for La Sabana Co. would be technology protection. A patent is a protective grant, to exclude others from making, using or selling the product. In order to patent an item in Colombia, it has to be reduced to practice; therefore, La Sabana Co. would need to have a project developed before the patent becomes accepted. For this reason Mr. Sanchez would need to have a construction project ready

to begin before acquiring the technology. Then he must produce the mold or equipment for that project in Mexico and ship it to Colombia. La Sabana Co. would therefore be able to protect the technology and investment even before implementing the production plant in Colombia and then use the money from this project to absorb some of the fixed costs needed for the in-house system implementation.

5.1.5 CONCLUSIONS

In summary, the implementation of the Meccano technology in the Colombian construction market causes several changes in La Sabana's value chain. A fundamental tool in carrying out these changes is creative, innovative engineers. Given this indispensable tool, the linkage between different company activities and research and development is a key factor in achieving a sustainable long term strategy. A potential element in the process of gaining competitive advantage with this construction technology is the possession of superior know-how of the parent technology and subtechnologies through the complete value chain of the company.

From the five forces point of view, the findings are, that the Meccano technology creates high entry barriers for new competitors and high exit barriers for actual competitors in industrialized construction. The buyers force helps to achieve the company's strategy due to the fact that buyers get more service, quality, and product performance. In other words, they get "more construction for the money". Application of the learning curve

obtained from R&D would be the key factor in reducing the power of suppliers in the long term strategy of the company. Technological development in the company chain has to be prepared to absorb the emergence of substitutes, therefore, R&D and "know-how people" play the main role against substitution by continuously improving the technology performance of the company. Finally, competitors will not abandon the market easily. They will lower prices and even earn low profits in order to be able to compete with non-technical bases.

A final issue for La Sabana company to assure competitive advantage, is to protect the technology even before the building of the factory in Colombia. This is particularly important because it will allow the company to pioneer the technological change and translates into first-mover advantages.

5.2 THE POTENTIAL FOR COMPETITIVE ADVANTAGE THROUGH TECHNOLOGICAL INNOVATION IN THE CASE STUDY

This section will review the case study presented previously, in terms of the concepts of the competitive advantage of technological development in construction engineering firms presented in chapters two and four.

The strong competition in the Colombian construction market and the need of searching for more specialized services to developers and owners have driven Constructora La Sabana Co. into technology. In order to formulate a coherent strategy for the development of the Meccano technology in Colombia, one segment

of the market has been selected among the different construction categories, and the estimate of the breakdown of output by technological levels and categories has been discussed.

5.2.1 TECHNOLOGY AND THE COMPANY VALUE CHAIN

By studying the influence of the technology in the company's value chain, it has been found that creative and talented engineers are the base to achieve competitive advantages with the Meccano technology. Given this prerequisite of a creative and talented engineering staff, three main elements have been considered in the implementation of the technology in Colombia. First, the involvement in a superior "know-how" in construction of large housing projects. Second, the involvement in a superior "know-how" in the production of the technology in Colombia and finally, the acquisition of rights of the Meccano construction process and Meccano production technology.

A largely interdependent combination of the following mechanisms is necessary for La Sabana Co. to obtain competitive advantage with the Meccano technology:

- experience. By increasing expertise via experience, the company and its value chain of activities must be attentive to continually improve the technology performance and take advantage of the learning curve results from such improvements;
- research and development. By increasing in house expertise via research and development, for example, the company helps to eliminate dependence on suppliers, and helps to create entry and

exit barriers for competitors. Further innovation and research in other technologies, such as computer-based data acquisition, automation, and robotics are fundamental for La Sabana Co. in order to be prepared for market changes and competitors development in the future. Subsequently, the implementation of the Meccano technology brings the need of preparing the firm to absorb subtechnologies in the different activities of the company value chain. R&D play an important role in the vertical integration of La Sabana Co. with other firms. By having collaborative arrangements with concrete testing companies and weld suppliers, the company's R&D is able to improve concrete performance in the construction process and to increase weld performance in the production process.

The different mechanisms discussed in order to sustain competitive advantage with the Meccano technology are:

- technology protection through patents, licenses and copyrights in order to pioneer the technological change and to translate into first-mover advantages;
- high capabilities not only in technological development but also in effective management systems and engineering services.

5.2.2 COMPETITORS AND THE COMPANY VALUE CHAIN

Among the important issues discussed in the La Sabana case is the role of competitors in construction with other industrialized systems. Four factors have to be specially controlled for a firm sustaining technology leadership in order to keep its competitive

advantage: first of all, protect the innovations and technology or technologies from competitors. Secondly, sustain high management and R&D capabilities in order to slow down the development of followers. Thirdly, be attentive to revolutionary technologies and be prepared to compete with technical basis and even switch the technology to a new production process with improved construction performance. Finally, be aware of radical changes in market demands in case it is necessary to leave the market.

CHAPTER VI

CONCLUSIONS AND IMPLICATIONS FOR TECHNOLOGICAL PROGRESS IN THE CONSTRUCTION INDUSTRY

This study has analyzed the construction industry in terms of the overall process of technology advancement common to all industries. The process of achieving a competitive advantage through technology consists of two basic steps.

First, the construction firms must define the needs for new technology and determine what incentives exist for meeting these needs. Second, the construction firms must develop and adopt new processes and products and improve upon the existing ones.

6.1 NEEDS AND MOTIVATIONS FOR NEW TECHNOLOGY IN CONSTRUCTION.

Construction has been slow in adopting new technologies. However, a number of trends are forcing the industry to borrow advanced technology from other disciplines. One is the increase in the technical complexity of constructed facilities. Another is that owners are demanding more of designers and constructors. Finally, some of the more competitive international companies are already involved in technology research. The study of the industry segmentation of present and potential construction markets is especially important for construction engineering firms in order to plan an effective technological strategy. A careful study of these

market segments reveals a further need for developing new technology, and provides the motivation for doing so.

The trends mentioned above indicate that construction companies must work harder to question past practices and to develop or adopt new construction technologies.

6.1.1 INTRODUCING INNOVATIONS

Investigations into product development and advances in the manufacturing process have identified means of bringing about innovations which may apply to construction. Direct ties to scientific advances are not as obvious in construction as in high-tech manufacturing. However, there are many examples of incremental improvements in the hardware and construction methods which make up construction technology. Simply the challenge of specific projects can bring about innovative solutions, generally in the form of improved methods or processes.

The intense competitive rivalry present in many segments of the industry also provides a strong incentive for finding the means to improve performance. New types of facilities provide new challenges. The necessity of meeting unique technical challenges on specific processes also provides a market incentive.

6.1.2 SOME MEANS TO IMPROVE PERFORMANCE IN CONSTRUCTION

In order to improve the performance of construction firms in meeting the demands of advanced construction technology, the following important issues must be considered: first, the

construction firms must develop their new technology with the cooperation of existing value chains and with the support of professional organizations. Second, construction firms must foster research and development initiatives in construction and process technologies. Third, they must apply the lessons they have learned from manufacturing, computer-based information technology, robotics and other construction industries in order to have both product and process innovations. Finally, construction firms must transfer complete technologies from other industries. For example, many current advances in automated data acquisition, automated process control, and robotics can benefit construction. Once all these considerations have been taken into account, the construction firms are ready to take the next step, which is to study market competition.

6.1.3 TECHNOLOGICAL DEVELOPMENT AND COMPETITION IN CONSTRUCTION

According to Porter's framework for the analysis of competition in specific industries, a firm will suffer a high level of competitive pressure when it is easy for new firms to enter the market, when both buyers and suppliers have high bargaining power, when there is an important threat of substitute products, and when rivalry among firms is high. All these competitive forces jointly determine the intensity of industry competition and the level of profitability. The strongest forces become crucial in strategy formulation. Companies able to manage these forces

correctly should be able to gain and sustain a competitive advantage. Technological innovation can help in this effort.

Competitive forces are pushing the construction industry into a greater use of technology as a source of competitive advantage in the following ways: first, buyers will always hire the contractor who is able to offer the best quality for the lowest cost; second, low entry barriers in the construction industry encourage companies to specialize in order to create entry barriers to future competitors; third, through technologies, companies can lower the power of suppliers by creating in-house knowledge of supplier technologies; and last, industries pursuing technological expertise will always be able to leave behind the intense rivalry of the current business conditions.

In order to achieve a complete definition of its needs, it is important for a construction firm to study all those factors which promote or discourage innovation. This study should be made before the firm implements its competitive strategy.

6.1.4 FACTORS PROMOTING OR DISCOURAGING INNOVATION IN CONSTRUCTION

The nature of the construction industry creates both advantages and disadvantages for innovation. One advantage is engineering and construction integration which can simplify the construction process requirements and decrease cost; another is that the uniqueness of a project provides not only a need for innovation but a challenge; a third advantage is the need for only a

modest initial capital investment leaving the possibility for further investment as needed; fourth, most construction companies are organized in such a way that they have a pool of experienced engineers to draw upon; fifth, the emphasis on process hinders imitation; last, the very uniqueness of each construction process encourages the invention of new methods to meet new demands.

There are fewer disadvantages. One is the lack of interest in automation resulting from the low capital intensity of the industry; another is the discouragement of new technology by construction codes, contractual practices and the organization of labor which complicate the institutional framework. A third disadvantage is the cyclical nature of the industry. Fourth, the suppliers to the construction industry have not ,themselves, kept pace with new technologies.

6.2 THE CONSTRUCTION FIRM VALUE CHAIN AND ITS ROLE IN CONSTRUCTION INNOVATION AND DEVELOPMENT

The second step in achieving a competitive advantage through technological development is based on research and development. Unlike the first step, which deals with market needs and market forces, the second step deals with the construction firms' value chains.

6.2.1 THE VALUE CHAIN AND SOURCES OF COMPETITIVE ADVANTAGE

Engineers with high technical capabilities and creativity are essential to construction firms which seek a position of technical leadership.

The first requirement for any construction firm which seeks success in such a competitive industry is a force of talented and creative engineers. A significant competitive advantage in construction is the possession of state of the art capabilities in one or more of the basic engineering technologies applicable to a competitive construction process.

The next basic source of competitive advantage is the possession of rights or licenses to a superior process technology. This may take the form of sole ownership of the process or restrictive rights for its use.

6.2.2 LEARNING AND RESEARCH IN CONSTRUCTION FIRMS

In the process of achieving competitiveness through innovation in construction, experience often offers a means of obtaining cost reduction over time. The most important mechanism however, is research and development. Firms that want to achieve technological leadership must implement in-house R&D capabilities which will facilitate continual innovative advances.

In order to sustain a competitive advantage through technology, continual technical advancements must be made. If the company owns the rights of a technology or a process of

technologies, continual improvements must be made in that process. In addition, the firm must maintain a competitive position both in labor management and in engineering services. Both these positions are supported by the company's performance within the value chain.

6.2.3 FIRM TECHNOLOGY AND THE ROLE OF COMPETITORS

A construction firm pursuing technological leadership must be aware of market changes. If a revolutionary product hits the market or an improved technology is introduced by competitors, affected companies may have to exit the market. However, the most common reactions of companies to strong competition are either to remain in the market earning low profits or to try to find their own source of competitive advantage to regain their leadership position. Companies with the best technological capabilities for innovation and creativeness will be in an excellent position to maintain their competitive advantage. In the long run only companies with strong linkages between research and development and their value chain activities will have a chance to sustain technological leadership in the competitive construction market.

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